PUBLIC DOCUMENT No. 31

MASSACHUSETTS AGRICULTURAL COLLEGE

THIRTY-THIRD ANNUAL REPORT OF THE MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

PARTS I AND II

Publication of this Document
approved by the
Supervisor of Administration.

THIRTY-THIRD ANNUAL REPORT

OF THE

MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

PART I

REPORT OF THE DIRECTOR AND OTHER OFFICERS

PART II

DETAILED REPORT OF THE EXPERIMENT STATION

BEING PARTS III AND IV OF THE FIFTY-EIGHTH ANNUAL REPORT OF THE MASSACHUSETTS AGRICULTURAL COLLEGE

A RECORD OF THE THIRTY-EIGHTH YEAR FROM THE FOUNDING OF THE STATE AGRICULTURAL EXPERIMENT STATION

CONTENTS.

Part I.

Part II.

Massachusetts Agricultural Experiment Station.

OFFICERS AND STAFF.

STATION STAFF.

Administration.

Sidney B. Haskell, B.Sc., *Director*.[1]
Fred W. Morse, M.Sc., *Acting Director*.[2]
Joseph B. Lindsey, Ph.D., *Vice-Director*.
Fred C. Kenney, *Treasurer*.
Charles R. Green, B.Agr., *Librarian*.
Mrs. Lucia G. Church, *Secretary to the Director*.
Miss F. Ethel Felton, A.B., *Clerk and Editorial Assistant*.

Agricultural Economics.

Alexander E. Cance, Ph.D., *Professor*.
Miss Lorian P. Jefferson, M.A., *Assistant Research Professor*.[3]

Agriculture.

William P. Brooks, Ph.D., *Consulting Agriculturist*.
Edwin F. Gaskill, B.Sc., *Assistant Research Professor*.
Robert L. Coffin, *Investigator*.

Botany.

A. Vincent Osmun, M.Sc., *Professor*.
George H. Chapman, Ph.D., *Research Professor*.[4]
Paul J. Anderson, Ph.D., *Professor*.
Orton L. Clark, B.Sc., *Assistant Professor*.
Webster S. Krout, M.A., *Assistant Research Professor*.
Miss Marguerite G. Ickis, M.A., *Curator*.
Alyn S. Ball, *Laboratory Assistant*.
Miss Ellen L. Welch, A.B., *Clerk*.[5]
Miss Gladys I. Miner, *Stenographer*.[6]

Cranberry Substation.

Henry J. Franklin, Ph.D., *Research Professor in Charge*.

---

[1] Appointed July 1, 1920.
[2] Until July 1, 1920.
[3] Appointed June 1, 1920.
[4] Absent on leave, Jan. 1 to March 15, 1920.
[5] Resigned Nov. 5, 1920.
[6] Appointed Oct. 1, 1920.

Entomology.	HENRY T. FERNALD, Ph.D., *Professor.* ARTHUR I. BOURNE, A.B., *Investigator.* HARLAN N. WORTHLEY, B.Sc., *Investigator.*[1] Miss BRIDIE E. O'DONNELL, *Stenographer.*
Horticulture.	FRANK A. WAUGH, M.Sc., *Head, Division of Horticulture.* FRED C. SEARS, M.Sc., *Professor of Pomology.* JACOB K. SHAW, Ph.D., *Research Professor of Pomology.*[2] HAROLD F. TOMPSON, B.Sc., *In Charge of Market-Garden Field Station.* WALTER W. CHENOWETH, M.Sc., *Professor of Horticultural Manufactures.* Miss ETHELYN STREETER, *Stenographer.*
Meteorology.	JOHN E. OSTRANDER, A.M., C.E., *Meteorologist.*
Microbiology.	CHARLES E. MARSHALL, Ph.D., *Professor.* ARAO ITANO, Ph.D., *Assistant Professor.*
Plant and Animal Chemistry.	JOSEPH B. LINDSEY, Ph.D., *Chemist.* EDWARD B. HOLLAND, Ph.D., *Research Professor.* FRED W. MORSE, M.Sc., *Research Professor.* HENRI D. HASKINS, B.Sc., *Official Chemist, Fertilizer Control.* PHILIP H. SMITH, M.Sc., *Official Chemist, Feed Control.* LEWELL S. WALKER, B.Sc., *Assistant Official Chemist, Fertilizer Control.* CARLETON P. JONES, M.Sc., *Assistant Research Professor.* CARLOS L. BEALS, M.Sc., *Assistant Research Professor.* ARTHUR M. CLARKE, A.B., *Assistant Chemist.*[3] Miss ANNE C. MESSER, B.A., *Investigator.* Miss ETHEL M. BRADLEY, B.A., *Analyst.* RAYMOND W. SWIFT, B.Sc., *Analyst.*[4] JAMES T. HOWARD, *Inspector.* HARRY L. ALLEN, *Laboratory Assistant.* JAMES R. ALCOCK, *Assistant in Animal Nutrition.* Miss REBECCA L. MELLOR, *Stenographer.* Miss CORA B. GROVER, *Stenographer, Control Service.*
Poultry Husbandry.	JOHN C. GRAHAM, B.Sc., *Professor.*[5] LOYAL F. PAYNE, B.Sc., *Acting Head of Department.*[6] HUBERT D. GOODALE, Ph.D., *Research Professor.* Miss RUBY SANBORN, *Clerk.* Miss DORIS TOWER, *Stenographer.*
Veterinary Science.	JAMES B. PAIGE, B.Sc., D.V.S., *Professor.* G. EDWARD GAGE, Ph.D., *Professor of Animal Pathology.* THOMAS G. HULL, Ph.D., *Assistant.*[7] JOHN B. LENTZ, V.M.D., *Assistant Research Professor.*[8]

1 Appointed July 1, 1920.
2 Reappointed June 1, 1920.
3 Resigned Sept. 30, 1920.
4 Appointed Oct. 1, 1920.
5 Reinstated April 1, 1920, after leave of absence.
6 Until April 1, 1920.
7 Temporary appointment, resigned Jan. 10, 1920.
8 Temporary appointment, Feb. 4 to May 31, 1920; permanent appointment, June 1, 1920.

REPORT OF THE DIRECTOR.

SIDNEY B. HASKELL.

The work of the Experiment Station this past year has been affected by many of the personal factors which so influenced work in other major subdivisions of the institution. Chief among these factors has been that of uncertainty as to the future, brought about by delay in securing the salary adjustment necessary to make the rate of pay somewhat more nearly comparable to the increased cost of living. This delay produced a feeling of uneasiness absolutely inimical to the good conduct of research work. Despite this fact, there have been but few changes in staff membership, these being as follows: —

Arthur M. Clarke resigned the position of assistant chemist on Sept. 30, 1920, and was succeeded by Mr. Raymond W. Swift, a graduate of the College with the class of 1920.

Dr. Thomas G. Hull, assistant in the Department of Veterinary Science, resigned Jan. 10, 1920. Dr. John B. Lentz, who resigned Sept. 18, 1919, having been in the service of the institution about three years, was reappointed February 4, as assistant research professor in the Department of Veterinary Science.

Prof. Fred W. Morse, who had been serving as acting director since the retirement of Dr. William P. Brooks, in March, 1918, resumed his work as research professor of chemistry on July 1.

Dr. Jacob G. Shaw was reappointed to the position of research professor of pomology, beginning June 1, 1920. Dr. Shaw comes back to this institution from service as head of the Department of Horticulture in the University of West Virginia.

Miss Lorian P. Jefferson, formerly assistant professor in the Division of Rural Social Science in the College, was appointed assistant research professor in agricultural economics, effective June 1.

Miss Ellen L. Welch, clerk in the Department of Botany, resigned Nov. 5, 1920, her position being taken by Miss Gladys I. Miner.

Changes in Departmental Organization.

With the development of larger bodies of knowledge in technical agricultural subjects has come increasing specialization. This has rendered necessary certain changes in organization in order that the work of the Experiment Station might conform to the departmental organization of the College. During the year just past the trustees approved the following changes, to become effective Dec. 1, 1920: —

Department of Horticulture, first recognized as an Experiment Station department in 1888, when the Hatch Experiment Station was organized, to be discontinued.

In place of the Department of Horticulture the following departments to be organized: —

Department of Pomology, with Prof. Fred C. Sears, head.

Department of Horticultural Manufactures, under the leadership of Prof. Walter W. Chenoweth.

Department of Market Gardening, and Market-Garden Field Station, under the leadership of Prof. H. F. Tompson.

The above changes in organization indicate no change in scope of work.

Publications of the Year.

The sole avenue through which the Experiment Station work can be taken at once to the people of the State lies in the publication of pamphlets and bulletins. Below is presented a list showing the publications of the year. Unfortunately, appropriations for publications were so small as to make it impossible to complete publication of all manuscripts which have been submitted. It is hoped that a larger sum will be available for the coming year.

Publications issued During 1920.

Annual Report.

Thirty-second annual report: —

Part I. Report of Director and Other Officers; 48 pages.

Part II. Detailed Report of the Experiment Station; 258 pages (being Bulletins Nos. 189–194).

Combined Contents and Index, Parts I and II; 20 pages.

Bulletins.

No. 195. Tobacco Investigations: Progress Report, by G. H. Chapman; 38 pages.
No. 196. Methods of Applying Manure, by Wm. P. Brooks; 22 pages.
No. 197. Nutritive Value of Cattle Feeds. 1. Velvet Bean Feed for Farm Stock, by J. B. Lindsey and C. L. Beals; 14 pages.
No. 198. Studies of Cranberries during Storage; 18 pages.
Chemical Studies, by F. W. Morse and C. P. Jones.
Fungi Studies, by B. A. Rudolph and H. J. Franklin.
No. 199. Broodiness in Domestic Fowl: Data concerning its Inheritance in the Rhode Island Red Breed, by H. D. Goodale, Ruby Sanborn and Donald White; 24 pages.
No. 200. Nutritive Value of Cattle Feeds. 2. Oat By-Products for Farm Stock, by J. B. Lindsey and C. L. Beals; 20 pages.

Bulletins, Popular Edition.

No. 200. Nutritive Value of Cattle Feeds. 2. Oat By-Products for Farm Stock, by J. B. Lindsey and C. L. Beals; 10 pages.

Bulletins, Control Series.

No. 13. Inspection of Commercial Feedstuffs, by Philip H. Smith and Ethel M. Bradley; 27 pages.
No. 14. Inspection of Commercial Fertilizers, by H. D. Haskins, L. W. Walker and A. M. Clarke; 92 pages.

Meteorological Reports.

Nos. 373–384, inclusive, 4 pages each.

The Project System.

An important development of the year is the attempt to organize all Experiment Station work on a definite project basis. This change is peculiarly necessary at the present time, owing to the fact that agricultural research has to a great degree passed beyond the simple "test" phase of its work. The problems which must now be undertaken are those which require in a great degree co-ordination between departments. Especially is this true of the work of the technical departments, for without exception these departments must make use of the fundamental sciences as tools in their investigation. It is neither practicable nor desirable, however, for each of these technical departments to duplicate the scientific equipment of

the fundamental scientific departments. Seemingly the only way in which effective co-operation can be brought about lies in securing the necessary co-ordinated study.

This work of project organization is not yet completed. The following, however, shows the projects either now under way, or so organized as to be under way in the very near future: —

Plant Nutrition — Comparative Fertilizer and Lime Tests.

Comparison of nitrogenous fertilizers; comparison of sulfate and muriate of potash; comparison of potash carriers; comparison of phosphate carriers; effects of plant foods alone and in combination; use of chemicals in supplementing stable manure for garden crops; orchard fertilization; experiments with Barium-Phosphate; relative value of different sources of lime; high potash *versus* high phosphoric acid fertilizers; study of bacterized peat; manure economy tests.

Plant Nutrition — Chemical and Biological Investigations.

Chemical effects of muriate and sulfate of potash; lime absorption and acidity of Field A; soil fertility as influenced by micro-organisms.

Plant Adaptation — Variety Tests.

Variety tests of fruits; asparagus variety test; limited variety test of vegetables; observations of summer forage crops.

Plant Physiology and Heredity.

Study of optimum conditions of light for plant response; the interrelation of stock and scion in apples; the genetic composition of peaches; study of tree characters of fruit varieties; study of the life processes of the strawberry.

Cultural Studies.

Cranberry bog management; cranberry bog weeds; blueberry culture; experiments in pruning apples; study of production with greenhouse lettuce and cucumbers.

Plant Protection — Insects.

Studies of insect outbreaks in various localities; limits of insect pests in Massachusetts; the number of broods of the codling moth in a year; dates of hatching of scale insects, and fixing dates for spraying such insects; insects affecting the cranberry; control of the onion maggot; control of the squash-vine borer; burning of foliage by insecticides; control of the squash bug; insect control on market-garden crops; study of the chemistry of arsenical insecticides.

Plant Protection — Fungous Troubles.

Investigation of onion diseases; experimental spraying for control of cucumber mildew under glass; methods for controlling lettuce drop; fungous diseases of cranberries (co-operative with the Bureau of Plant Industry, United States Department of Agriculture).

Plant Studies — Miscellaneous.

Study of tobacco sickness and tobacco-sick soils; studies of cranberry storage and shipping conditions.

Animal Nutrition.

Comparative feeding tests and feeding trials of new materials; record of the Station herd; digestion experiments with sheep; a study of rations for horses.

Animal Physiology.

A study of the chemistry of butter fat, etc.; determination of the mode of inheritance of various characters in poultry.

Animal Pathology.

Methods of diagnosis of bacillary white diarrhea; elimination of disease in poultry; study and control of poultry diseases in College and Station flocks; study and control of bovine abortion; study of hog cholera and the use of serum.

Meteorological Studies.

Weather observations, with especial attention to frost protection; areas in which immunity from early and late frosts may be expected, and the consequent effect on selection of crops; general weather observations.

Studies in Food Distribution.

Methods and costs of distribution of tobacco and onions; study of consumers' co-operative associations (in co-operation with the Bureau of Markets, United States Department of Agriculture).

Studies in Food Preservation.

Canning investigations.

Progress in some of these investigations is handicapped by a shortage of land. This condition is due primarily to the encroachment of buildings on the old Experiment Station grounds, but in addition is due to the fact that land once used for certain types of experiment is rendered useless for other kinds of experiments for long periods of years. Therefore, while it is true that several of the present field experiments had best be brought to a close, yet the land involved will not become immediately available for other investigations. It is therefore hoped that the projects now in the hands of the trustees for the purchase of the Brooks Farm and of the Tuxbury land will receive the support of the Legislature.

In this connection it should be stated that the time is coming when the Experiment Station must branch out and undertake thoroughgoing work in other sections of the State. A start in this direction was made about ten years ago when the Cranberry Station was first organized. The success of this station

has been so marked as to gain the unqualified support of cranberry growers. The Market-Garden Field Station was later established at North Lexington, although in the beginning not on an experimental basis. The next step, logically, is to go west of the Connecticut and establish an experimental substation in the hills of western Hampshire, Franklin or Hampden county. Many technical problems of production must be solved before these hill farms can be brought back to their old-time productive condition.

Additional Assistants.

An unexpected result of the organization and development of the county farm bureaus has been the increased demand made on the Experiment Station for service in investigating problems affecting agriculture. The inability of the Station to meet these demands is causing criticism. While there is no doubt that much of this criticism arises from ignorance rather than knowledge, yet the fact is that the farmers of the State, as represented by their county agricultural agents, are more eager than ever for knowledge and for facts. The Experiment Station cannot ignore these demands, and is making every effort in its power to meet them. At present, however, investigations under way are so numerous and so important as to make it almost imperative that we secure additional assistants to give attention to the new problems which are constantly arising. Those needed in the immediate future are as follows: —

Assistant to the Director.
Clerk and graduate assistant, Department of Agricultural Economics.
Assistant research professor, Department of Botany.
Assistant research professor, Department of Horticultural Manufactures.
Assistant in experimental market gardening, Market-Garden Field Station.
Assistant in experimental pomology and graduate assistant, Department of Pomology.
Assistant research professor and two graduate assistants, Department of Microbiology.
Poultry pathologist,[1] Department of Veterinary Science.
Research professor and laboratory assistant, Department of Farm Management.
Research professor, Department of Rural Sociology.
Poultry pathologist [1] and collector of blood samples, Poultry Disease Law.

---

[1] One-half time.

Acknowledgment.

In conclusion I wish to acknowledge the hearty and loyal co-operation accorded me by the different members of the Experiment Station staff. I believe that the time which is usually lost through change in any administrative organization will be somewhat decreased through the services thus freely given. Particularly I wish to express my appreciation of the co-operation given me by Dr. William P. Brooks, formerly director of the Station and now consulting agriculturist; Prof. F. W. Morse, formerly acting director; and Dr. J. B. Lindsey, vice-director of the Station. All of these men have spared no pains in placing at my disposal all information needed in prosecuting the work.

REPORT OF THE TREASURER.

ANNUAL REPORT

Of Fred C. Kenney, Treasurer of the Massachusetts Agricultural Experiment Station of the Massachusetts Agricultural College, for the Year ending June 30, 1920.

United States Appropriations, 1919–20.

		Hatch Fund.	Adams Fund.
Dr.			
To receipts from the Treasurer of the United States, as per appropriations for fiscal year ended June 30, 1921, under acts of Congress approved March 2, 1887, and March 16, 1906,		$15,000 00	$15,000 00
Cr.			
Adams: —			
By salaries,	$14,448 31		
labor,	272 00		
chemicals and laboratory supplies,	4 58		
seeds, plants and sundry supplies,	58 89		
fertilizers,	216 22		15,000 00
	$15,000 00		
Hatch: —			
By salaries,	$14,081 50		
labor,	918 50	15,000 00	
	$15,000 00		

State Appropriations.

Cash balance brought forward from last fiscal year,	$21,992 62
Cash received from State Treasurer,	55,875 80
fees,	155 77
sales,	5,530 79
miscellaneous,	2,022 02
	$85,577 00

Cash paid for salaries,	$26,206 90
labor,	14,591 80
publications,	3,182 72
postage and stationery,	1,387 81
freight and express,	303 45
heat, light, water and power,	353 52
chemicals and laboratory supplies,	945 99
seeds, plants and sundry supplies,	1,659 57
fertilizer,	763 08
feeding stuffs,	1,007 98
library,	873 08
tools, machinery and appliances,	942 87
furniture and fixtures,	190 55
scientific apparatus and specimens,	198 12
live stock,	15 00
traveling expenses,	2,091 49
contingent expenses,	37 65
buildings and land,	1,124 22
Remitted to State Treasurer,	29,701 20
Total,	$85,577 00

REPORT OF THE DEPARTMENT OF AGRICULTURAL ECONOMICS.

ALEXANDER E. CANCE.

The research work of the department has been carried on along three lines: —

Consumers' Co-operation in Massachusetts. — For about two months the department co-operated with the Federal Bureau of Markets in a brief study of consumers' co-operation in Massachusetts. Since the period given to this work was short, it was impossible to do more than study types of co-operative enterprises among consumers, no effort being made to arrive at the total membership in such organizations or their total volume of business.

The forms of so-called co-operative consumers' organizations found in the State were: —

(*a*) Buying clubs, — unincorporated groups which buy supplies together but keep no stock of goods on hand and distribute orders by the easiest method possible.

(*b*) Stores, organized, owned and operated by the consumers, each member owning so much stock in the business and having a vote in all business matters. These are incorporated groups, some few of which have been doing business for a number of years.

(*c*) So-called co-operative stores: in reality stores maintained for the employees of a manufacturing company by the company itself. At these stores goods are offered at less than the price asked at neighboring retail stores, the company carrying all the overhead expenses of rent, heat, light and clerk hire. One firm frankly acknowledged that they expected to lose $10,000 a year on the enterprise. On the other hand, another store was found which was started by the firm for its

employees, but which has gradually passed into the hands of the employees, the firm now having nothing to do with the conduct of the store, and supplying nothing but the quarters which it occupies.

This brief study revealed an increasing interest in co-operation among consumers. Stores are being opened by all classes, but chiefly among factory employees. Labor leaders are interested in the movement, which is especially strong among foreigners, particularly the Italians and Finns, the latter having sixteen stores of various kinds in the State.

A number of requests were received for assistance in securing farm products for these consumers' associations. These were turned over to the Extension professor of the department, who has taken steps to render the assistance asked.

Farm Ownership in Massachusetts. — The second line of research which has been carried on throughout the year is a study of farm ownership in Massachusetts. A questionnaire was prepared and has been filled out by 650 farmers of the State, some of the schedules being secured by mail and some by personal visits. The county agents of several counties have rendered most valuable assistance in this matter. Although the study is yet incomplete, some interesting facts with regard to the steps to farm ownership are already in hand. It is expected that a bulletin embodying the results of this study will be ready for publication within the year.

Onion Supply and Distribution in the Connecticut Valley. — The department is bringing up to date the data on onion supply and distribution in the Connecticut valley previously published in Bulletin No. 169. The supply, weekly shipments, destinations, prices, storage stocks and recent developments in preparation and marketing are the principal data studies. It is the purpose of the department to publish during 1921 a supplement to Bulletin No. 169 embodying these new data.

Proposed Research Work for the Coming Year.

Supply and Distribution of Connecticut Valley Tobacco. — It is proposed to gather similar information with reference to the supply and distribution of cigar leaf tobacco in the Connecticut valley to supplement Bulletin No. 193 published in 1919.

This bulletin, entitled "The Supply and Distribution of Connecticut Valley Cigar-leaf Tobacco," was prepared by Samuel H. DeVault, at that time assistant in the department. The bulletin has been of such service to both growers and dealers that it is deemed advisable to bring up to date the information therein presented.

Local Balance of Trade. — The line of investigation on which the emphasis will be laid, with the approval of the trustees, is a study of the local balance of trade in certain markets. Specifically it is suggested that this study be made in Fitchburg, Lynn and Lawrence, with perhaps some others to be added later. The products to be considered will be those which cannot be grown locally; products which might profitably be grown but for some reason are not (for this portion of the study the assistance of various members of the Division of Agriculture will be enlisted); products which are grown locally but not in sufficient quantity to supply the local market; products grown locally in quantity sufficient to supply the local market with a surplus for export; products which are exported with shipments returned to the local market or duplicated by shipments from outside areas.

Clerical assistance is much needed in order to expedite the work. At present the only clerical help available is that assigned to the instructional staff. The work demands a competent clerk capable of doing stenographic work and tabulations, and of looking up statistical data.

REPORT OF THE DEPARTMENT OF AGRICULTURE.

E. F. GASKILL.

The work of the Agricultural Department during the past year has progressed along the same general lines as heretofore. A large part of the work has had to do with a study of different phases of the problem of soil fertility, which has necessitated the care and management of a large number of field plots. Many of these plots have received a continuous treatment since the organization of the Experiment Station in 1888, while some, owing to the disappearance of certain fertilizer materials from the market during the war and the scarcity of others, have undergone material changes and rearrangements. Despite these changes there are several significant facts brought out by the crop yields of the season just past.

Field A, or the Nitrogen Field. — Three plots on Field A (the nitrogen field) gave an average crop of hay and rowen of slightly more than 3,100 pounds per acre. This yield, while not large, was significant in that these plots had received no nitrogen in either fertilizer or manure for a period of thirty years. The records on this series of plots are becoming increasingly valuable year by year, indicating a distinct gain of nitrogen through the growth of leguminous crops. Another record from this field of more than incidental value is the fact that although a mixture of grasses and clovers was sown last year, this year's crop was practically free of clovers except on the no-nitrogen plots. Once again the fact that large amounts of commercial nitrogen are somewhat antagonistic to the growth of clovers is strikingly demonstrated.

The Response of Crops to Potash. — The response of crops to potash when used on different types of soil is brought out by a

comparison of the yields on two of the Experiment Station fields. The soil on the South Soil Test is considered a light loam, while that on Field G is a heavy, silt loam. In both fields there are plots to which no potash has been applied for years, but which have received annual applications of nitrogen and phosphoric acid. The rates of application of these plant-food elements per acre are shown in the following table: —

Field.	Total Nitrogen (Pounds).	Total Phosphoric Acid (Pounds).	Total Potash (Pounds).
South Soil Test,	About 25 (as nitrate),	51 (from acid phosphate),	80
Field G,	39 (from nitrate), 20 (from tankage),	57½ (from acid phosphate), 30 (from tankage),	135

The increase due to the use of potash on these fields for different crops over a long term of years is shown in the following table: —

Crop.	South Soil Test.		Field G.	
	Number of Years grown.	Increase per Acre due to Potash.	Number of Years grown.	Increase per Acre due to Potash.
Corn,	9	32½ bushels,	3	½ bushel.
Soy beans,	1	12.8 bushels,	4	¼ bushel.
Mixed hay,	6	738½ pounds,	3	1,735½ pounds.[1]
Rowen,	4	405 pounds,	–	–
Clover,	–	–	2	598 pounds.
Potatoes,	–	–	5	54.1 bushels.

[1] Includes hay and rowen.

These two fields are scarcely more than 200 yards apart. The soil survey map published by the Bureau of Soils, United States Department of Agriculture, classifies them together. Were the land still used as a farm instead of for experimental purposes, the two areas would probably be thrown together in the same field, and put to the same uses. Yet we have one part where without potash corn cannot grow; another part where the use of liberal quantities of fertilizer potash makes

scarcely a perceptible difference in the yield of corn. So varied are our New England soils!

The Effect of Nitrogen, Phosphoric Acid and Potash on Corn and Grass. — An opportunity was offered during the past two seasons to study the same crop on three of our experimental fields, — namely, the nitrogen field, the potash field and the phosphate field. During 1919 these three fields were in corn. In one case the limiting factor was nitrogen, in another potash and in another phosphoric acid. On all of these fields there were certain plots that have received incomplete mixtures; for example, the check plots on the potash field received no potash. The rates of application of the several plant-food elements per acre are shown in the following table: —

Field.	Total Nitrogen (Pounds).	Total Phosphoric Acid (Pounds).	Total Potash (Pounds).
Nitrogen Field,	45,	80 (from acid phosphate),	125
Potash Field,	39 (from nitrate),	57½ (from acid phosphate),	135
	20 (from tankage),	30 (from tankage),	
Phosphate Field,	56 (from nitrate),	96,	150
	20 (from ammonia),		
	14.6 (from organic nitrogen),		

The yields of hard corn follow, the figures representing bushels per acre: —

Field.	Incomplete Fertilizer or Check.	Complete Fertilizer.	Gain of Complete over Incomplete.
Nitrogen Field,	48 7 (P+K)	66 3	17 6
Potash Field,	49 6 (N+P)	64 3	14 7
Phosphate Field,	57 6 (N+K)	65.0	7 4

The significance of these figures lies in their uniformity. The average product of complete fertilizer treatment on all three fields is practically the same.

During the past season these same fields were in grass and clover, the seed mixture sown being the same in all cases. The

hay yields on these fields were as follows, the figures representing pounds per acre: —

Field.	Incomplete Fertilizer or Check.	Complete Fertilizer.	Gain of Complete over Incomplete.
Nitrogen Field, ...	3,148 3	5,163 4	2,015 1
Potash Field, ...	5,941 0	6,210 3	266 3
Phosphate Field, ...	7,060 0	7,902.4	842 4

Comparison of the grass yields of this year with the corn yields of last year is illuminating. Last year the complete fertilizer treatment, varied as it was on the different soils, gave uniform yields of corn. This year the same treatment gave rather diverse yields of hay. All of this happened, however, within a section of land which might well be compassed by the boundaries of a 5-acre lot. Very evidently the peculiar soil conditions in New England make very difficult the drawing of generalizations from fertility field experiments.

REPORT OF THE DEPARTMENT OF BOTANY.

A. VINCENT OSMUN.

The work of the Department of Botany during the last year has not deviated in any important respect from that previously reported. Research work, the normal function of the Experiment Station, continued to engage the major attention of the staff. While no new projects were started, certain changes and additions were made in some of those under way.

Report on Project Work.

The report on project work is one of progress. Some lines of investigation are essentially completed. Several bulletins and technical papers are in course of preparation by members of the staff, and will be presented for publication as speedily as other work will permit.

Tobacco Investigations. — Tobacco investigations, under the leadership of Dr. G. H. Chapman, have so developed that it has become advisable to discontinue the plots located on privately owned farms during the last four years. The project has been reorganized, and in the future plots will be conducted on College-owned land controlled by the Station. A progress report on the project was published in March of the present year as Bulletin No. 195.

Investigation of Onion Diseases. — Investigation of onion smut under the project on onion diseases has continued, with results on the field plots confirmatory of those previously obtained. A large amount of painstaking work on the morphology and life history of the onion smut fungus, *Urocystis cepulæ*, has been carried on by Dr. P. J. Anderson, who expects to publish a technical paper on these phases of the investigation during the next year.

Optimum Conditions of Light for Plant Response. — Prof. O. L. Clark has continued to accumulate experimental data in his study of optimum light requirements of plants. That phase of the work embracing study of the influence of different light intensities on plants grown under cloth of different meshes has been discontinued after several years of field tests. A new feature of this work now being planned will deal with the influence of ultra-violet light on plants.

Plant Diseases of the Year.

While the plant diseases coming under our observation were as numerous and varied as in almost any other year, few new or unusual troubles were among them.

Tobacco. — A bacterial disease of tobacco, known in the South as wildfire, was reported for the first time in this State, though there is evidence to support the belief that it was present at least two years earlier. During the curing and fermentation season for tobacco, the weather conditions favored development of such troubles as pole-sweat, stem-rot, canker and moldy or musty tobacco. Considerable loss ensued, and there were many calls for assistance. An Extension bulletin, entitled "Curing and Fermentation Troubles of Tobacco," and an Extension circular on "Tobacco Wildfire," were prepared by Dr. Chapman.

Tomato. — Late in September, Septoria leaf-spot of tomato, caused by *Septoria lycopersici* Speg., was discovered in a small garden in Amherst where it had caused severe defoliation of the vines. The disease previously has been noted on two occasions in greenhouses of the State, but this is the first report of its occurrence out of doors in Massachusetts. In the Middle Atlantic States this disease causes large losses, and is rated as the most serious disease of the tomato in that region. Should it gain a foothold in this State it might become a problem of considerable economic importance.

Carrot. — What appears to be a new disease of the carrot was first called to our attention in 1918 at the Market-Garden Field Station by Prof. H. F. Tompson. The disease seems to be very destructive at times, and while it received some attention in 1919 and 1920, it is deserving of careful investigation, and

will be made the subject of a project. Its cause has not been determined, but it appears to be of fungous origin.

Eggplant. — In 1919 a disease of eggplant, evidenced by wilting and death of the entire plant, was reported from the market-garden sections of the State. One large grower lost a large part of his crop. Preliminary investigation failed to establish definitely the cause of the trouble, and in the absence of this information the grower was advised to plant in 1920 on new land not previously used for this crop. This was done, with the result that the disease in question appeared in only one row, and it developed that this row — the only one of the 1920 planting — was located on a section of the land where the disease occurred in 1919. During the summer Mr. Krout definitely determined the cause of the disease to be a fungus of the genus Verticillium. This disease has been previously reported in other parts of the country, but has had little attention from investigators.

Potato. — Late-blight of potato, always a possible menace to the crop, took a heavy toll the last season. The disease was first observed August 9. Abnormally high humidity throughout August and September, with heavy rainfall in the latter month, furnished conditions highly favorable to the development of the causal fungus. As usual, fields carefully and systematically sprayed with homemade Bordeaux mixture suffered the least. Up to the time of this writing many reports of storage rot due to late-blight have come to the department, and it is probable that the loss from this source will be large.

Apples. — A heavy crop of apples in a season of weather conditions which favored the development of scab and black-rot meant a large initial loss from these diseases in the orchard. The heaviest outbreaks occurred in the eastern part of the State, where early varieties, such as Gravenstein and Yellow Transparent, suffered from black-rot, and McIntosh from scab. In one small area growers estimate that these diseases reduced the value of their crop fully $200,000. The best control measures known have been employed in eastern Massachusetts, and their partial failure indicates that some factor or factors have been overlooked. This points to just one thing, — the need of investigation to determine how these diseases may be

controlled. Because it is apparent that there are unknown factors in the problem, investigational work must start with a careful and detailed study of causal organisms and the relation of environmental conditions to their development. Without this fundamental knowledge the problem of control cannot be attacked with any degree of intelligence. The need of instituting work along this line was pointed out in our last annual report. The experience of the past year has made the need even more urgent. The department is ready to undertake the work whenever financial provisions can be made. This, however, is but one of many lines of investigational work pressing for attention by the Department of Botany. Some of these were referred to in our last report.

Seed Work.

There has been the usual amount of seed work, including germination tests of a variety of vegetable, cereal and grass seeds, and many samples of tobacco and onion seeds; examination of grass seeds to determine purity and the presence of weed seeds; and cleaning and separation of tobacco, onion, lettuce, parsnip and celery seeds.

Extension Work.

Plant disease diagnosis, with the prescribing of remedial measures, demanded more time and attention than in any previous year. The constantly increasing burden of this work tends more and more to interfere with the efficient prosecution of research, and emphasizes the need of an Extension specialist in plant diseases, which has been frequently urged. It is most desirable that this need be met in the near future by the appointment of an Extension plant pathologist to be a member of the staff of the department. The necessity of keeping this type of work within the Department of Botany cannot be pressed too strongly, as it is essential that the department, through the close co-operation of all members of its staff, be constantly and intimately in touch with all the plant disease problems of the State.

REPORT OF THE DEPARTMENT OF CHEMISTRY.

J. B. LINDSEY.

Research Section.

Butter Fat Studies. — Experiments to note the effect of coconut, corn, peanut and soy bean oils upon the chemical character of butter fat have been made during the past year, but owing to the interference of other work the laboratory studies have not been completed. Methods, either direct or indirect, have already been devised for determining with a reasonable degree of accuracy the percentages of the several soluble and insoluble fatty acids of butter fat, and the work of studying food influence is being prosecuted as fast as time will permit.

Insecticides and Fungicides. — A considerable amount of work has been done upon insecticides and fungicides in co-operation with the Department of Entomology, and a number of proprietary products have been examined.

Several poison cases have been investigated for other departments of the College. While this latter is not research work, it was quite necessary and required the services of a specialist.

A method of analysis of lime-sulfur mixtures has been developed which will be submitted for publication in some chemical journal. The method is adapted to the analysis of any of the water-soluble sulfides.

Animal Nutrition. — A thorough study has been made of the nutritive value of oat by-products, — hulls, middlings, and the mixture of the two, known as mill run oat feed, — and the results are now in press.

Digestion studies with sheep have been completed with the

several oat by-products, and also with peanut skins, shells and meal, coffee refuse, coconut meal and cottonseed meal.

Metabolizable energy trials of wheat bran, cottonseed and linseed meals, corn cobs and different varieties of hay have been made with horses. The results in some cases have proved so contradictory that repetitions are now in progress.

Experiments with twelve pigs have just been completed, to note the nutritive and economic value of feeding different amounts of semi-solid and evaporated buttermilk. Because of the high prices of grain as compared with the market price of the pork produced the experiment was not a financial success. The least loss, however, was sustained on the pigs receiving grain alone, followed in succession by those receiving rations composed of grain plus tankage, grain plus powdered buttermilk, and grain plus semi-solid buttermilk.

A demonstrative trial was undertaken with two groups of six pigs each, to observe the value of pasturage and partial soiling as supplements to grain feeding. Because of imperfect control the results were not as satisfactory as desired, but they tend to confirm similar observations elsewhere, which have demonstrated that this method of pork production is well worthy of serious trial by farmers in Massachusetts. It is doubtful, however, in view of the high cost of labor, if much time can be spent in growing forage crops. An alfalfa or clover pasture, or even a fertile grass pasture, could be used, supplemented by grain from self-feeders.

Forage Crops. — Observations in planting soy beans with corn in different ways — mixed together in the drill in the proportion of two-thirds corn and one-third beans, together in the hill, and between the corn hills — were undertaken, but owing to the unsatisfactory character of the bean seed the results were in no way conclusive.

Sudan grass did not prove successful, for in spite of a reasonable amount of seed per acre — 24 pounds broadcast — a very light stand was secured. This condition has repeated itself with us for several years. The seed was sown upon a light, well-drained loam, June 15. Barnyard millet and early amber sorghum have proved more desirable forage crops.

Alfalfa, red clover and sweet clover have each been seeded

together with peas and oats for two successive years. After the peas and oats were cut and removed, these legumes have come on well, and have produced a very satisfactory stand. The rains during the past two years were frequent, which favored their growth. If the season had been dry during the development of the peas and oats, it is doubtful if the legumes would have succeeded by this method of sowing. The clover grew so fast as to enable us to make a cutting in early September.

Respiration of Cranberries. — The study of cranberry respiration was concluded in the early part of the year. The results of the investigation and previous studies of chemical changes during storage have been prepared for publication in a bulletin which is now in press.

Soil Studies. — A striking recurrence on the plots of Field A in 1919, and again this spring, of the toxic effect on plant growth of sulfate of ammonia led to a repetition of some of the research work on the soils of plots 5 and 6, with reference to the presence of soluble salts of manganese, iron and aluminum. Large volumes of water extracts of the soils were prepared and concentrated by evaporation. The residues were analyzed, and amounts of manganese, iron and aluminum were determined by weight. There was found to be present at least 175 parts sulfate of manganese in 1,000,000 parts of dry soil, equivalent to 350 pounds in the upper 8 inches of an acre. This is sufficient to be very poisonous to many kinds of plants. Aluminum was present in much less quantity in the extract, and iron in little more than traces. These results confirm the conclusions of Ruprecht and Morse in previous bulletins of the Experiment Station. A study of the history of the field for thirty-two years has shown that injury on the plots receiving sulfate of ammonia has been most marked in seasons when droughts have occurred in the early summer. The addition of lime to the soil prevents the injury by promoting the formation of sulfate of lime instead of the other salts. Examination of limed soils from these plots showed much smaller quantities of manganese and aluminum in a soluble form, and larger quantities of lime.

Fertilizer Section.

Fertilizer Inspection. — During the season of 1920, 98 manufacturers, importers and dealers have secured certificates for the sale of 583 brands of fertilizer, fertilizing materials and agricultural limes. In the year's inspection, 7,403 tons of fertilizer were sampled, necessitating the sampling of 17,919 sacks; 193 towns were visited; 1,311 samples, representing 492 distinct brands, were drawn from stock found in the possession of 716 different agents or owners; and 738 analyses were made. The table shows the number of brands of the different materials which were registered and sampled, as well as the number of analyses made: —

Material.	Brands registered.	Brands collected.	Number of Analyses.
Complete fertilizers,	292	250	331
Ammoniated superphosphates,	119	95	117
Superphosphate and potash,	6	3	3
Ground bone, tankage and dry ground fish,	54	51	78
Nitrogen compounds,	40	34	100
Phosphoric acid and potash compounds,	45	31	49
Wood ashes,	2	4	36
Lime compounds,	25	24	24
Totals,	583	492	738

A declaration of the tonnage of commercial fertilizers sold in Massachusetts between the dates of Jan. 1, 1920, and July 1, 1920, showed a total of 57,845 tons, divided as follows: —

	Tons
Mixed fertilizers,	47,842
Unmixed fertilizers,	10,003

Full details of the fertilizer inspection work may be found in Bulletin No. 14, Control Series, published in December, 1920.

Miscellaneous Analytical Work. — During the last two months in 1919 and the first three months in 1920 the usual amount of co-operative chemical work was done on problems of the Agricultural Department of the Experiment Station, and on

vegetation experiments conducted by the fertilizer control section.

The fertilizer section has also analyzed 281 different substances sent in by farmers and by the various departments of the Experiment Station. In case of the large number of soil samples which have been examined, the tests made have been largely confined to a determination of the lime absorption capacity of the soils and their content of organic matter. It might be said with reference to the testing of the great variety of fertilizer by-products that an effort has been made, as in the past, to give reliable information in each case as to the best method of utilizing said by-products.

Vegetation Tests. — The following experiments were planned in the fertilizer section, but the details of growing the crops have been left, in all cases, to the Agricultural Department.

A pot experiment comprising 60 pots, with millet as a crop, was conducted to study the availability of the water insoluble organic nitrogen in certain commercial fertilizers found in the 1916 fertilizer inspection work. Many of these samples were considered of suspicious quality so far as their organic nitrogen source was concerned. The purpose of the experiment was to make further studies of the results of laboratory methods as compared with those obtained in vegetation tests. This work was planned several years ago, but due to a scarcity of coal it has not been possible to operate the greenhouse during the winter months, and this season presented the first opportunity for making the test.

An experiment comprising 12 pots, with oats as the crop, was conducted to show the residual effect of peat mixtures with and without commercial bacteria. This was a continuation of a pot experiment begun in 1919.

Another experiment was carried out, using 23 pots with tomatoes as the crop, to compare the effect of bacterized peat with peat which contained no commercial bacteria. This was to parallel work conducted in the field with tomatoes and potatoes during the seasons of 1919 and 1920.

The tile experiment with apatite and barium sulfide, begun in 1919, was continued this season, with oats followed by buckwheat as the crop. This experiment comprises 46 tile.

A field experiment with bacterized peat, comprising two fields of eight plots each, was continued from the previous year. The purpose of this experiment was the comparison of a mixture of bacterized peat with one containing no commercial bacteria. The crops (tomatoes and potatoes) were rotated, the field which was used for potatoes in 1919 being used for tomatoes this season, and *vice versa.*

Feed and Dairy Section.

The Feeding Stuffs Law (Acts and Resolves for 1912, Chapter 527). — During the year 1,002 samples of feeding stuffs were collected and analyzed. The results of the year's work, together with a discussion of some feeding problems, have been published as Bulletin No. 13 of the Control Series. The official inspector visited 204 dealers located in 113 towns. One thousand four hundred and sixty brands of feeding stuffs were registered for sale in Massachusetts by 305 manufacturers.

On account of the greatly increased cost of carrying out the provisions of the feeding stuffs act with no increase in appropriation, local prosecutions have not been attempted, the Experiment Station continuing to depend upon the co-operation of the Federal authorities for action against violators of the law when the feeds entered into interstate commerce. On the whole, the market, while not entirely free from low-grade material, has been quite free from misrepresentation and fraud.

The Dairy Law (Acts and Resolves for 1912, Chapter 218). — The dairy law, so-called, requires operators of the Babcock test, where such test is used as a basis of payment for milk or cream, or for the purposes of inspection, to secure a certificate of proficiency from the Experiment Station. Fifty-one applicants were given the required examination and received certificates. The act requires, also, that all glassware used by licensed operators be tested for accuracy, and so marked. Six thousand and eighty-four pieces of glassware have been tested, of which only 13 pieces were condemned. In addition to the preceding, an annual inspection of machines and apparatus is also required. This inspection was carried out by Mr. J. T. Howard, authorized deputy, who visited 6 creameries, 33 milk depots and 46

milk inspection laboratories. Reinspections on account of repairs ordered will be necessary at nine places.

Miscellaneous Work. — Considerable time is used in making analyses of feedstuffs and dairy products sent in by citizens of the State, and of samples in connection with feeding experiments at the Experiment Station. Waters from wells or springs used as family supplies are also examined.

Considerable time has also been devoted to work not easily reported in terms of statistics, such as giving advice or information, either verbally or through correspondence, relative to feeding stuffs found in the Massachusetts markets, and to the formulating of rations. While such work is more properly an Extension function, an attempt is made to answer such questions where the answer is found in the chemical work with which we are directly concerned.

Testing of Pure-bred Cows for Advanced Registry. — The supervision of advanced registry is taking an increasing amount of time each year, and it is believed that it will be necessary very soon to make other arrangements in order to care for the work more adequately. Not less than nine and as many as sixteen men have been employed in making the two-day monthly tests. For the year ending Dec. 1, 1919, 4,150 two-day tests were reported; for the year just past 5,820 were reported, — an increase of 1,668 over the previous year. The number of cows on yearly test increased in one year from 416 to 519; the number of farms, from 58 to 72.

Summary of Two-day Test Work, December, 1919, through November, 1920.

Month.	Number of Supervisors, Whole or Part Time.	Number of Cows tested.						Number of Herds visited.					
		Guernsey.	Jersey.	Ayrshire.	Short-horn.	Holstein.	Totals.	Guernsey	Jersey.	Ayrshire.	Short-horn.	Holstein.	Totals.
December,	10	166	130	85	4	31	416	31	11	10	2	4	58
January,	9	169	114	88	4	39	414	34	12	10	2	8	66
February,	16	178	138	79	8	52	455	35	11	10	3	9	68
March,	14	161	128	100	15	50	454	33	12	10	4	9	68
April,	11	161	130	107	19	72	489	32	10	11	4	10	67
May,	13	158	120	106	21	77	482	32	9	11	4	12	68
June,	10	167	118	103	21	89	498	29	10	11	4	12	66
July,	12	197	115	104	23	88	527	40	12	11	4	10	77
August,	12	175	113	107	24	91	510	30	11	11	4	11	67
September,	13	189	118	104	26	90	527	33	12	12	4	11	72
October,	11	198	120	103	28	80	529	31	12	12	4	9	71
November,	12	190	112	103	28	86	519	35	11	12	3	11	72
Totals,	-	2,109	1,456	1,189	221	845	5,820	-	-	-	-	-	820

The short-time tests for the Holstein Friesian Association did not fall off to the extent hoped for; in fact, about 46 more cows were reported than for the previous year. Statistics for the Holstein work follow: —

Number of farms visited,	32
Supervisors employed,	39
Reports turned in:	
120-day,	1
100-day,	1
60-day,	1
30-day,	58
14-day,	13
7-day,	261

Numerical Summary of Laboratory Work.

Samples sent to the Station.

Water,	60
Milk,	344
Cream,	378
Ice cream,	1
Breast milk,	2
Feedstuffs,	145
Fertilizers,	100
Lime products,	6
Soils for lime absorption capacity and organic matter tests,	137
Soils for complete or partial chemical analysis,	20
Arsenic determinations,	2
Vinegar,	7
Insecticides,	9
Cider for soluble copper,	9
Tobacco,	12
Control Work.	
Fertilizers,	1,311
Feedstuffs,	1,002
Samples Analyzed in Connection with Experiments.	
Milk,	168
Feedstuffs,	114
Fæces,	49
Urine,	14
Dry matter determinations on pot experiments,	288
Nitrogen determinations on pot experiments,	96
Phosphoric acid determinations on pot experiments,	44
Potash determinations on pot experiments,	48
Total,	4,366

REPORT OF THE CRANBERRY STATION.

H. J. FRANKLIN.

Investigational Work.

Insects. — The study of cranberry insect problems in general was continued. In co-operation with Mr. Walter Holmes, the gypsy-moth superintendent for southeastern Massachusetts, tests were made to determine the effectiveness of the open nozzle in spraying to control the gypsy moth on the bogs. General observations were also made concerning the occasional remarkable decrease in severe gypsy infestations during the development of the worms.

Hitherto unknown parasites of the cranberry girdler (*Crambus hortuellus*) were reared. A new control for this pest was developed, — namely, spraying with nicotine sulfate to kill the moths. In connection with this work it was observed that the insecticide was also destructive to leaf-hoppers and spring-tails which usually infest in great numbers the vines of bogs that are not reflowed, and probably reduce their vitality considerably. These tests and observations added materially to the mass of information from which must be developed the most practical program for spraying bogs which have water supplies for winter flowage only.

Tests were conducted to determine what strength of nicotine sulfate is most feasible for use in a spray to kill the moths of the black-head fire worm (*Rhopobota vacciniana*). Satisfactory results were obtained.

The brown span worm (*Epelis truncataria* var. *faxonii*) was unusually prevalent, the moths appearing in great numbers on even more bogs than in 1919. Many requests for advice on the control of this pest were answered, with the result that it did little harm except on a few neglected bogs. Important ob-

servations were made concerning the worm counts that precede serious injury by this insect.

The green span worm (*Cymatophora sulphurea*) was also unusually prevalent this season, and it completely destroyed what promised to be a very good crop on several acres in Duxbury. Important new facts about the life history of this species were learned.

By extensive examinations and counts it was found that the egg parasite (*Trichogramma minuta*) of the fruit worm was less prevalent than usual.

Important new observations concerning the habits of the root grub (*Amphicoma vulpina*) were made.

Five field meetings (in Rochester, Carver, Plymouth, Wareham and Sandwich) were held with cranberry growers to demonstrate the use of the insect-collecting net in discovering and determining the severity of certain insect infestations in their early stages. These meetings were planned as a special effort in the control of the gypsy moth, but the other open-feeding caterpillars often found damaging the bogs, such as span worms and army worms, were also discussed. A supply of insect nets had been prepared, and more than five dozen of them were sold to the growers for use on their bogs.

Weather Observations. — Weather observations were made as in previous years, in co-operation with the Weather Bureau, daily reports being telegraphed to the district forecaster in Boston.

A new method of making minimum temperature calculations for frost predicting, based on the Station records of 1913 to 1917, inclusive, was published in the "Monthly Weather Review" by the writer. Further records and studies were made during the season for the purpose of testing and improving this method. In forecasting for the local cranberry growers the method proved accurate enough to be very useful. Heretofore opinions concerning possible frosts have been given, with a few exceptions, to the local growers and those in the town of Carver only, the distribution of the warnings in Carver having been made possible by the generous co-operation of Mr. L. M. Rogers, manager of the Atwood Bog Company. This season, through the courtesy of the New England Telephone

and Telegraph Company, arrangements have been made to give out frost predictions in both the afternoon and evening to all the growers on the Cape who want them. This system of distribution was not completed until after the beginning of the fall frost period, but it should prove useful hereafter.

Disease Control. — Extensive further tests of arsenate of lead as a treatment of diseases causing cranberry decay were conducted, with results that strongly confirm those of former years.

Fertilizer Tests. — The fertilizer tests which had been conducted for about twelve years with generally negative results were discontinued.

Varieties. — The study of the characteristics of the cranberry varieties cultivated on the Cape was continued, special attention being given to seed counts. As a part of this work, small plantings of the Pride and Wales Henry varieties were made at the station bog.

Storage Tests. — At the end of the season storage tests were conducted to determine the effect of different containers on the rate of size shrinkage of the sound berries.

Blueberry Work. — Work with the blueberry plantation progressed satisfactorily, much more extensive budding of selected stock being done than heretofore. Satisfactory drainage of the plantation was provided by new construction. The quarter acre of cultivated plants yielded 147 quarts of fine berries, the largest of which were 20 millimeters in diameter. This seems a fair crop, as most of the plants were seedlings only five years old. The fruit was all sold locally at moderate prices.

For cranberry variety studies and the proper development of the blueberry work several acres more of rough land are needed, and an early appropriation should be made for its purchase.

Extension Work.

As usual, much time was spent in what should be classified as Extension work. This work was made more effective than heretofore through the presentation to the Station, by the Cape Cod Cranberry Growers' Association, of a Ford runabout.

This enabled the writer to visit bogs in distant towns more freely. This extension of the field of operation not only made the Station more serviceable to the growers, but also yielded some valuable results in the way of new observations.

Yield of Cranberries.

The Station bog yielded a crop of about 900 barrels, and this fruit sold at good prices, so the Station was more than self-supporting this year.

REPORT OF THE DEPARTMENT OF ENTOMOLOGY.

H. T. FERNALD AND A. I. BOURNE.

Report of Project Work.

The Onion Maggot. — Studies on control of the onion maggot have been seriously interfered with by the reduction of acreage of onions raised, owing to lack of labor in the Experiment Station. Only a small part of the acreage usually available could be obtained for experimental work on this subject, and the tests were less satisfactory for that reason. Such results as were secured, however, were distinctly favorable, and if an unrestricted opportunity to continue the work in 1921 can be arranged, and the year proves to be a "maggot year," it is probable that this project can be brought to an end.

Importance of the Codling Moth. — Studies on the importance and time of appearance of the codling moth have made satisfactory progress. Considerable information has been added to that already obtained, but the results thus far, it must be acknowledged, are rather perplexing. The usual directions as to treatment for this insect include spraying with arsenate of lead three to four weeks after the calyx spray. This time is rather too late for a fungicide spray, which should be applied about two weeks after the calyx spray. If the codling moth spray can be as successfully applied earlier, with the fungicide, a distinct saving will be made. The data thus far gathered are insufficient to settle this point, and the entire project evidently calls for further observations.

Studies on Common Scales. — Observations on the dates of appearance of the crawling young of our common scales have, as stated last year, shown that the original idea of the experiment could not be held to, but another basis for the work has

been found and promises to prove sound. If so, the data already accumulated will be of great value. Added to this as collateral items, observations on the dates of appearance of many of our other common insects and of the development of various plants in the spring promise much of interest along the same line.

Tests of Standard Insecticides. — Studies on the burning of foliage by insecticides are drawing toward an end. The results thus far are being tabulated and prepared for publication.

Studies on Digger Wasps. — These studies are progressing, though slowly. The project is a much larger one than was at first supposed, and with little time available for it, any marked advance in a single year is impossible.

The Squash-vine Borer. — This pest has caused a large amount of injury in Massachusetts the last few years, and a study of the insect and methods for controlling it have therefore been taken up this season. It is too early as yet to expect results, but several facts which may prove of value have already been obtained.

The Squash Bug. — This pest has also been studied to some extent the past summer. Work on it will be continued next year.

Studies of Spray Materials.

Studies of several materials used in spraying were made during the season, and the results follow: —

Aphicide. — There have been times when nicotine sulfate 40 per cent was not available on the market, owing either to an unusual demand or faulty distribution. At such times an effective substitute to use against aphids is desirable. Kerosene emulsion, employed for many years for these insects, is troublesome to make, and frequently fails to give good results. Anything which is an effective aphicide and also reasonable in price is, therefore, desirable to add to our list of insecticides.

Aphicide is a new material manufactured as a substitute for the nicotine sprays in controlling plant lice, and it was therefore tested during the season. Two samples were provided, one apparently more concentrated than the other. Both were clear liquids, the (presumably) weaker being almost colorless, the

other having a slight yellowish-brown tinge. Both mixed easily with water, and showed little tendency to separate out of the mixture on standing. The directions provided by the manufacturers for mixing called for $\frac{3}{4}$ to 1 per cent of the material and $\frac{1}{2}$ per cent of soap. The formula would therefore be: —

Aphicide,	$\frac{3}{4}$ to 1 part
Soap,	$\frac{1}{2}$ part
Water,	$98\frac{1}{2}$ to $98\frac{3}{4}$ parts

Such accuracy as this proved unnecessary, and various strengths of the material were tested, as the formula just given was too weak to kill the aphids. At 5 and 6 per cent, both grades of Aphicide proved very efficient, but were injurious to tender foliage. An increase of the amount of soap was then tried, and it was found that 1 per cent of soap with 4 per cent of Aphicide gave very satisfactory results without injuring the plants.

The conclusions reached as a result of these tests are that 4 parts of Aphicide and 1 part of soap in 95 parts of water make an effective material to use against aphids, and will not, at least under ordinary conditions, injure foliage.

Sulco V. B. — Tests of this material were undertaken at the request of one of the county agricultural agents who was much impressed by the comprehensive claims made by its manufacturers, these being that it is an insecticide, a fungicide and to some extent a repellent.

The material is a thick, heavy, oily substance readily miscible with water, from which it does not separate to any great extent until after standing for about twenty-four hours. It is claimed to be a mixture of a fish oil, sulfur and carbolic acid. The directions for application supplied by the manufacturers were to mix 1 part of the material with 25 parts of water for use against aphids, 1 to 30 for mites on evergreens, 1 to 100, with 2 pounds of arsenate of lead powder, against cucumber beetles, and 1 to 20 for ants in lawns.

Tests were made with this material for the control of ants, of plant lice, and of mites on evergreens, as a repellent for adult squash bugs, and to kill the eggs and young. Its effects on foliage, alone and with arsenate of lead, were also tested. In these tests the directions for preparation were fol-

lowed until the necessity for a change became evident. As a repellent against ants, it killed a few which were actually hit by the material; the others were not affected, nor was the prosperity of the colony as a whole checked perceptibly. Grass and other plants around the nests were killed. Against squash bugs it showed no repellent value and did not kill the eggs. It killed the young bugs, but when used strong enough to do this it killed the squash leaves also. Against mites on evergreens it proved fairly effective, but when any large percentage was killed, its strength had been necessarily increased to a point where it was not safe for the leaves. In the case of plant lice the strength recommended proved dangerous to the foliage of the plants, though killing the lice. Further tests, diluting the material at the rate of 1 to 60, and even 1 to 70, gave excellent results with the insects and no leaf injury.

Mixed with arsenate of lead the same results were obtained, and the conclusion was finally reached that Sulco V. B., at the strength recommended by its makers, is unsafe for use on most kinds of foliage; and that, when diluted to a point where it will not cause foliage injury, it is ineffective as an insecticide except for plant lice. For these pests, however, it can be diluted to a point where the leaves will not be injured and still kill the insects.

White Arsenic as an Insecticide in Bordeaux Mixture. — Some recent experiments, reported by Sanders and Kelsall (Proceedings of the Entomological Society of Nova Scotia, No. 5, for 1919), using arsenic instead of arsenate of lead or arsenate of lime in Bordeaux mixture, made it seem desirable to give a little attention to this subject. White or common arsenic costs less than the other arsenicals, "is the most concentrated form of arsenic, and consequently suffers least from freight rates, occupies less space, and entails the handling of less weight." If it can be used as safely and effectively as the other insecticides in combination with Bordeaux mixture, it should largely replace them, at least for some purposes.

Tests of this mixture on potatoes were made during the season, a very finely divided sample of arsenic being used. To prepare 50 gallons of the spray, half a pound each of white arsenic and fresh, unslaked lime were used. The lime was slaked in just enough water to keep the action brisk, and the

arsenic was slowly added during the slaking and thoroughly mixed in. After the slaking had been completed, water sufficient to make 5 gallons was added, and the whole thoroughly stirred. A sack containing 5 pounds of copper sulfate was then suspended in the mixture and shaken frequently until the copper sulfate had entirely dissolved. About a day later, when ready to spray, 5 pounds of lime were slaked in a few gallons of water, and diluted to make 25 gallons. The other mixture, prepared the day before, was also then diluted with water to make 25 gallons, and the two lots were poured together, stirred and sprayed.

It is evident that as a result of this work the material sprayed is no longer arsenic itself. It is probable that it, at least in part, combines with the copper, forming copper arsenite, which alone is often very injurious to foliage, but in this case is rendered non-injurious by the lime present. The Bordeaux mixture made in this way was green in color. Its suspension did not quite equal that of ordinary Bordeaux-arsenate of lead, but it adhered to the leaves fully as well. No leaf injury was observed in any case where this material was used, and good protection from potato insects was secured. No blight appeared on the potatoes.

The amounts of lead arsenate, both in dry form and as paste, required to furnish the same amount of poison (expressed in terms of metallic arsenic) as was supplied by one-half pound of white arsenic, together with the relative costs of the three materials, are as follows: —

Material.	Metallic Arsenic (Per Cent).	Material required to furnish Equal Amounts of Metallic Arsenic.	
		Pounds.	Cost.
White arsenic,	75	½	$0 11[1]
Dry lead arsenate,	21	2	84
Lead arsenate paste,	11	4	1 00

[1] In 50-pound lots.

Evidently the white arsenic is by far the cheaper material to use. There is a little extra labor in preparing the Bordeaux mixture with arsenic as compared with the use of the other

materials, but in practice this proved to be only a few minutes.

Where very finely divided arsenic can be obtained, therefore, its use in homemade Bordeaux mixture seems to be profitable, at least as a spray for potatoes.

Dry Sulfides as Substitutes for the Lime-sulfur Concentrate. — Dry sulfides have appeared on the market in recent years as substitutes for the liquid lime-sulfur. Reports as to their value have been conflicting, some claiming that they give good results, while others consider them worthless. The difficulties with the concentrate are several. Being a liquid it is more inconvenient and more costly to ship, and the material itself will not keep long if exposed to the air. It is also spoiled by freezing. These difficulties are all avoided by the use of dry materials, and if their effectiveness as insecticides is equal to that of the concentrate, the latter will surely be entirely discarded after a time.

This department has no opportunity to carry out field tests of these materials, but with the aid of the Chemical Department of the Station has made some studies on their composition.

The lime-sulfur concentrate contains calcium thiosulfate and calcium polysulfide. It is the general belief, sustained by experimental tests, that the polysulfide is the active agent of the mixture. The relative efficiency of these compounds is best measured in terms of their sulfur content. An investigation was made of the amount of polysulfide sulfur present in the lime-sulfur concentrate, in dry lime-sulfur, in barium tetrasulfide (B. T. S.), and in soluble sulfur (sodium polysulfide). In the comparisons which follow, spray made from the lime-sulfur concentrate, strength 1 to 8, was taken as the standard: —

Material.	Polysulfide Sulfur Present (Per Cent).	50 Gallons Spray made from Manufacturer's Directions.			50 Gallons Spray, Standard Strength.	
		Amount of Material used.	Cost.	Polysulfide Sulfur (Per Cent).	Amount of Material required.	Cost.
Lime-sulfur concentrate.	25.00	5 5/9 gallons	$1 10	3.50	5 5/9 gallons	$1 10
Dry lime-sulfur, .	49.86	10 pounds	1 30	1.18	30 pounds	3 90
Barium tetrasulfide .	43.19	11 pounds	1 54	1.12	34 pounds	4 80
Soluble sulfur, . .	47.97	12½ pounds	1 25	1.41	31 pounds	3 10

Evidently, then, the concentrate is the cheapest material by far. It is also evident that at the strengths advised by their makers, the other substances will have much less of the active agent present, and should be far less effective than the concentrate.

On the other hand, many who have used these materials report good results. Is this due to defective observations, prejudice in favor of materials so easily handled, or is it correct? If the latter, the question at once arises whether the concentrate is not stronger at 1 to 8 than is really necessary, and whether the other weaker materials are not, after all, strong enough for the work. To answer this, extensive field experiments under all kinds of conditions will be needed. It is possible that for years we have been using the concentrate stronger than is necessary, and that a greater dilution, bringing the percentage of polysulfide sulfur per barrel of spray down from 3.5 to about 1.25 per cent, would give equally good results. If this should prove to be true, the relative costs of the different materials would not be greatly affected, however, and the concentrate would in any case be the cheapest of the four by a considerable amount.

Extension Work.

There has been the usual demand upon this department for work of an Extension nature. Rather more than a quarter of the entire time of one man has been required to attend to duties of this kind. Correspondence, telephone and office calls, visits to places where assistance was needed, fumigation work, the preparation and demonstration of exhibits at fairs and during Farmers' Week, have made up this total.

The College Apiary.

The care of the College Apiary was under the supervision of Mr. J. L. Byard until about the middle of July. Unfortunately, Mr. Byard was taken ill at that time, and during the remainder of the year his work was necessarily carried on by the men in this department. Had this not been done, the colonies of bees would have been lost and the beekeeping

work would have come to an end, but the time required to prevent this loss to the College greatly reduced the amount of experimental work it was possible to do. Mr. Byard's death the last of November means the loss to the College of a faithful and industrious worker who had been for a number of years connected with the apiary here, and who had given liberally of his time and energy to the welfare of the work.

Insects of the Year.

While many kinds of insects were actively at work during the year, no outbreak such as that of the bean caterpillar in 1919 developed in the State in 1920.

As a matter of record it may be noted here that the gypsy moth made its appearance in Amherst in 1920 for the first time, but only in small numbers. Pelham and Belchertown are now also infested.

REPORT OF THE DEPARTMENT OF HORTICULTURAL MANUFACTURES.

W. W. CHENOWETH.

This department has but recently been organized, and because of crowded conditions in the laboratory, meager equipment and lack of efficient research assistants, the investigations carried on thus far are only preliminary to larger things to be taken up later. However, much valuable work has been done along the following lines: —

Jelly Making. — This is being studied from the standpoint of economic production. Results show that by proper handling of the fruit the yield may be increased two to three times the amount generally obtained by household methods; also that jelly of highest quality is produced where the amount of sugar is reduced to one-half or less than one-half the amount generally used. This fact has been of tremendous importance in recent years because of the sugar shortage.

The Economic Values of Varieties of Fruits for Manufacturing Purposes. — These investigations include both the small fruits and tree fruits. There is no doubt that varieties of fruit vary in their natural adaptability for canning and for the manufacturing of many fruit products.

Fruit Juices. — The manufacture and preservation of fruit juices for beverage purposes is an interesting and important problem. Many thousands of dollars worth of fruits are wasted annually in Massachusetts while our markets are supplied with fruit juices from the fruit plantations of the West. The work here also includes studies of improved methods in the home manufacture of vinegar.

Canning. — Study is being made of those factors that influ-

ence the processing period of canned foods, as well as studies of varieties of fruits best adapted to canning.

Cranberries. — The utilization of poor-grade cranberries is being studied this season.

When the necessary facilities are provided, the department plans to intensify and enlarge the above projects, and in addition to start further investigations looking to the solution of other perplexing problems connected with the preservation of fruits and vegetables.

REPORT OF THE DEPARTMENT OF HORTICULTURE.

J. K. SHAW.

There are at present four projects dealing with pomological questions under active investigation: —

The Interrelation of Stock and Scion in Apples. — The orchards devoted to this project have made satisfactory growth, and the usual records have been taken during the year. Some tabulations have been made which indicate that the stock materially modifies the growth of the tree, but these must accumulate for several more years before safe conclusions may be drawn.

The Genetic Composition of Peaches. — The orchard planted for this work has made fair growth, and several additional varieties desired have been secured. It will be a year or two yet before the trees come into bearing so as to permit extensive pollination work. A small quantity of pits of known parentage was planted in the spring of 1920, but for some unknown reason none of them grew.

A Study of Tree Characters of Fruit Varieties. — Last year some work was done on the study of variation and its relation to the theory of senility, and it is proposed to give some more time to this next year. Plans are made for a somewhat extensive study of leaf characters, which it is hoped may be completed during the season of 1921.

Pruning Young Apple Trees with Special Reference to Head Formation. — This orchard has made splendid growth, and is showing substantial results from the different methods of pruning. Unfortunately it was not pruned in the spring of 1920, and this omission will have an effect on the future be-

havior of the trees. The pruning in the spring of 1921 will, so far as possible, correct this omission.

Temperature Observation Work. — A large amount of data has accumulated from this work, and is now being tabulated and studied as to its relation to peach and apple growing.

Several new lines of work are under consideration in the hope that they may be undertaken in the near future. These center around the general question of soil management and fertilization of apples, peaches and bush fruits. Means of promoting the bud hardiness of peach should have some consideration, and we could well undertake some further work in pruning.

REPORT OF THE MARKET-GARDEN FIELD STATION.

H. F. TOMPSON.

Report on Project Work.

Manure Economy Test. — This was somewhat upset by the late spring, shortage of labor and insect injury, but the records show consistent progress.

Barium-Phosphate Test. — In the second season's test Barium-Phosphate has shown no particular benefit over acid phosphate as a carrier of phosphoric acid, and in several instances has seemed less efficient. Two tests were carried out, — one similar to that of 1919, the other with complete fertilizers, Barium-Phosphate being substituted for acid phosphate in one mixture. The crops under test were beets, carrots, cabbage, lettuce and spinach.

Martha Washington Asparagus. — The one-quarter acre plot of this asparagus has developed in a satisfactory manner. The first cutting was made the past season. Wide variation in size and yield is noticeable in different plants. Plans are under way for tests of individual plants to determine yields and characters, with a view to an elimination of the less productive units.

Limited Variety Tests. — These tests have proved of much interest, and point to some avenues of investigation which are projected for the future. The strain and variety test of tomatoes has been of much value, and indicates the possibility that ecological factors are of more importance for this crop than is commonly supposed.

Greenhouse Cucumbers. — In the greenhouses there has been a second test of cucumbers conducted in a similar manner to that of 1919. The cold, cloudy spring interfered with this

project, more particularly as it was necessary to depend upon heat from the sun, the heating plant not being completed. Ten strains of the greenhouse type of cucumbers, mostly from local growers, were under test, to determine the comparative yields. The first planting was made on the 3d of April, and picking did not begin until late in June. A bad attack of anthracnose greatly damaged the test. The total yield per plant averaged about one-half that of 1919. The variation in yield between strains, so far as this test indicated, was so slight as to leave the choice to market quality. In this there was considerable difference. As the Boston market calls for a long dark green type, the Belleville strain appeared superior, and the yields were approximately the same as for some of the shorter varieties.

Greenhouse Lettuce. — The project of improvement of lettuce for greenhouse production was started in the fall of 1920, with a test of some thirty-five strains and varieties of lettuce, collected from local growers and leading seedsmen in this country and abroad. By the 30th of November the test had not proceeded far enough to show results.

Increase in Equipment.

The equipment for experimental work has been increased by the completion of the heating plant and oil-burning apparatus, also the purchase of two additional recording thermometers. Each greenhouse is now equipped with self-registering thermometers, and a complete record of night and day temperatures is being filed.

REPORT OF THE DEPARTMENT OF METEOROLOGY.

J. E. OSTRANDER.

The work of this department has been continued along the lines of previous years without material change. The character of the work requires that after a definite form of records has been adopted it should be adhered to without much change if the records of different years are to be compared.

The regular semi-daily readings of the several meteorological instruments have been made and tabulated, and the self-recording instruments kept adjusted and running without any material stoppage. As some of the instruments have been in constant use for more than thirty years, frequent adjustments have been necessary. The time has come when a beginning should be made toward a renewal of the more important instruments. The more important records have been tabulated in the same form as when the station was started, so that comparisons from year to year may readily be made. The monthly bulletin of four pages has been prepared and published promptly at the close of each month.

The usual voluntary observer's reports have been sent to the Boston office of the United States Weather Bureau each month, and during the growing season weekly reports on crop conditions, precipitation, temperature and sunshine have been furnished the same office. Arrangements have been made to furnish the usual snow and ice reports to the Weather Bureau, as the snow and ice bulletin is to be issued again after having been temporarily discontinued during the war period.

Many requests for specific data regarding the weather on certain dates have been received and answered during the

year. The information asked for usually related to temperature at the time crops may have been injured in shipment, unusually heavy precipitation, wind direction or wind movement, or the general character of the day. This particular feature of the work of the department has greatly increased in the last few years.

REPORT OF THE DEPARTMENT OF MICROBIOLOGY.

C. E. MARSHALL.

The Experiment Station work in this department may be enumerated under three heads: —

Food. — The only workers in this field for the past year have been two graduate assistants giving half time, — Mr. Conrad H. Leiber and Miss Mary Garvey, the latter retiring from the work Oct. 1, 1920. Owing to this situation progress lags. Dr. Arao Itano, who gave some time to food study during the year, with the assistance of Miss Garvey, concluded a phase of this field of study, report on which will be withheld until another aspect of the subject is covered. The study in hand is a continuation of that of last year.

Dairy. — Although no recognition is given to the dairy studies by the Experiment Station, it may not be amiss to mention the fact that Mr. James Neill and Mr. R. C. Avery are engaged upon two very interesting themes out of which much is anticipated.

The past year two articles have been published in "Dairy Science," giving the results of the department's work on the De Laval studies: —

"Clarification of Milk," by Charles E. Marshall and E. G. Hood, together with Arthur N. Julian, S. G. Mutkekar and Max S. Marshall, in Vol. III, No. 4, July, 1920.

"An Association Study of *Streptococcus Lacticus* and *Bacillus Subtilis*," by Max S. Marshall, in Vol. III, No. 5, September, 1920.

Another article has been prepared by Max S. Marshall dealing with the possibilities of the clarifier, which furnishes a basis for its future development.

Soil. — Progress has been made in the study of microbial changes of organic matter of the soil. A step in the investigation of the problem, carbon dioxide determination (started in connection with Mr. L. C. Whitaker, who resigned July 1), has been developed and is now ready for publication. The study of the microbial decomposition of cellulose has been started in association with Mr. J. R. Sanborn.

Miscellaneous Work. — The analytical work of the department may be summed as follows: —

Bacterial counts on milk samples,	815
Water samples tested,	12
Medical specimens,	125

Legume cultures to the number of 299 were distributed.

REPORT OF THE DEPARTMENT OF POULTRY HUSBANDRY.

H. D. GOODALE.

The Elimination of Disease.

The chief item of interest in the work of the year is the drive made against disease, especially paralysis. The plan consisted in hatching from the old stock as usual, but taking the day-old chicks directly from the machines to a quarantined range where they were grown to maturity. At the close of the breeding season all old stock was sent to market, and the plant thoroughly cleaned and disinfected. In October the young stock was transferred to the renovated plant. The experiment was completely successful as far as the quarantined range was concerned, but a report on the remainder of the experiment cannot be made until more time has elapsed.

Project Work.

The fusion of the high-producing line and the non-broody line is complete. Broody birds still appear and doubtless will continue to appear for several years. Judging from this fall's performance, the egg production of this strain is likely to exceed that of any previous flock. Much more rapid progress could be made in the development of the high-producing strain if a thousand pullets could be trap-nested each year for the next two or three years.

A considerable amount of work of technical interest has been done on the reproductive organs.

Tillson Farm.

The assignment of the Tillson Farm to the Poultry Department will remove many hindrances to the progress of the experiments as soon as the transfer is completed and the farm is properly equipped.

DEPARTMENT OF VETERINARY SCIENCE.

JAMES B. PAIGE, D.V.S.

With the rapid multiplication of activities in the department during the past four or five years, the administrative work has increased to the point where it requires the attention of the head of the department for the greater part of the time for which he is responsible to the Experiment Station. The direction of the activities of the members of the staff, the preparation and development of the projects, conferences, keeping of accounts, etc., leave little time for the prosecution of investigational studies.

Diagnosis.

For many years it has been the practice in the department to invite the stockmen throughout the State to send in material from sick or dead animals for examination and diagnosis. This material comes from all species of farm animals. It frequently furnishes the best of specimens for study and use in the classrooms and laboratories. It also enables the department to keep in touch with the different diseases of farm animals throughout the State, and to locate the existence of an unusual disease in a particular locality. A report giving details of post-mortem findings, the cause of the trouble, nature of the disease and means of prevention and treatment is sent to the one sending in the material. By this means we feel that the department is rendering a valuable service to the stock owners of the State, along the line of disease eradication and control.

Correspondence.

From the preceding paragraph it is evident that a large amount of correspondence is necessary in connection with the diagnosis work. Each letter has to be of a personal nature, as hardly any two cases are exactly alike. In addition, many letters are received asking for information and advice relative to the treatment of diseases of the different species of farm animals. Conferences with stockmen from different localities frequently follow correspondence.

Control Work.

Nearly all of the more serious contagious and infectious diseases of farm animals are placed by law under the control of the Division of Animal Industry of the Department of Conservation. Among them may be noted bovine tuberculosis, glanders and mange of horses, hog cholera and others. There are some, however, belonging to the class, such as fowl cholera, fowl typhoid and bacillary white diarrhea, that do not engage the attention of the Division of Animal Industry.

Under an act of the Legislature passed in 1919 this department was given a small appropriation for the purpose of testing poultry for the elimination of disease. The entire amount appropriated, $3,000, has been expended in testing fowls for the diagnosis and control of bacillary white diarrhea. The act provides that a fee not to exceed 7 cents per bird may be charged for each bird tested. From Dec. 1, 1919, to Dec. 1, 1920, there were tested 19,982 birds, with receipts of $1,398.74. In addition to these receipts the department provided 12,810 leg bands for identification of birds from which blood samples were taken, for which the owners paid $64.05, making the total receipts $1,462.79. Deducting this amount from the amount of the appropriation, we have $1,537.21 as the total cost to the Commonwealth for this particular line of work.

Under the existing conditions of high cost of materials, travel, maintenance, etc., $3,000 was hardly sufficient to carry on the work to the satisfaction of all parties interested. In fact, it became necessary to suspend operations through the three

summer months. Under normal conditions there are but few demands for testing in summer. The hatching season is over and the poultrymen have not made up their matings for the next season. With a sufficiently large appropriation to carry on the work continuously throughout the year, however, the summer months could be used to very good advantage by the department in visiting the flocks tested earlier in the season and checking up the work, a procedure necessary in any effort directed toward the suppression and elimination of any animal disease.

It is to be hoped that the General Court at its next session will considerably increase the appropriation under the special act of May 23, 1919, thereby enabling us to carry on the work continuously throughout the year, to extend the field of operations to include a larger number of flocks, and thus to increase the services of the department for the benefit of the poultry keepers of the Commonwealth.

Investigations.

Bacillary White Diarrhea in Chicks; a Study concerning the Diagnosis of Bacterium Pullorum infection in the Domestic Fowl. — This project is being conducted as an Adams fund study, and the details are in charge of Dr. George Edward Gage. The laboratory studies of the problem have been completed, and a start has already been made in the preparation of the manuscript for a bulletin, which, it is expected, will be ready for the printer early the coming year.

Studies relative to Hog Cholera; its Complications, Prevention and Inherited Immunity. — These investigations are being carried on with a herd of from 75 to 100 hogs kept by a farmer here in Amherst and fed upon raw garbage that is collected about town, which, it is reasonable to infer, is liable at any time to be contaminated with pork scraps from localities where hog cholera exists. It is a well-recognized fact that many of the outbreaks of hog cholera occurring among Massachusetts hogs have their origin in fresh pork scraps that find their way into garbage. The work already done in connection with this experiment has shown beyond a doubt that hog cholera of the usual type can be prevented by the use of anti-hog cholera

serum and virus. There is also strong evidence that one application of the simultaneous treatment to weaned pigs possessing an inherited immunity is sufficient to protect the animal against the usual type of hog cholera throughout its life. The usual practice, at present, is to give weaned pigs a single dose of anti-hog cholera serum, and then, at the age of twelve to fourteen weeks, to give both serum and virus. If it is found that the simultaneous treatment at the weaning time is sufficient to protect throughout the life of the pig, the expense and trouble of two treatments may be avoided.

Special Problems.

Early in the year two special problems came to the department, each of which demanded immediate attention. A number of cows at the farm barn calved prematurely, and it was thought that contagious abortion had gained a foothold in the herd. At the poultry plant disease was ravaging the flock, as many as ten to fifteen birds being found dead on successive days. The condition became so acute that the farm committee of the Board of Trustees met to consider ways and means of dealing with the situation. As a result of their deliberations it was decided to procure the services of a graduate veterinarian to take the matter in hand, under the direction of the head of the Veterinary Department. Dr. John B. Lentz, a graduate of the Veterinary Department of the University of Pennsylvania, who had been a member of the staff of the Veterinary Department of the Experiment Station in charge of the poultry disease elimination work, and who, after his discharge from the service, had resigned his position, was secured to come to the department to take charge of these two special problems. He reported for service early in February, and at once began an investigation of each problem.

It was found at the farm barn that a considerable number of cows had given birth prematurely, but there was no conclusive evidence that the contagious form of abortion existed in the herd. A considerable number of cases of sterility, vaginitis, metritis and other complications of abortion existed in the herd. All of these conditions were taken in hand, and

the individual cows given appropriate treatment. Although the work is still in progress and cannot be completed until the time arrives for the next crop of calves, a marked improvement as regards the premature births and complications is to be noted at the present time. Cows that have not been bred successfully for many months are in calf, with every indication that they will carry the fœtus the full period of gestation.

Conditions at the poultry plant were far more serious than at the farm barn. A large number of birds showed symptoms of disease and unthriftiness. When the Veterinary Department was placed in charge of the poultry plant, early in February, it seemed probable that by appropriate methods of treatment of the entire flock of about 2,000 birds, it might be possible to eliminate the disease factor without resort to destruction of the entire flock. It soon developed, however, that we were able to make but little progress in arresting the spread of disease. After consultation with the representatives of the poultry staff, and acting largely upon their statement that the stock on the plant was not entirely satisfactory from the poultry husbandry point of view, it was decided to completely eliminate the old flock and clean and disinfect the premises, leaving them vacant for as long a time as possible before bringing a new flock onto the place.

To provide birds to take the place of those destroyed, eggs from the tested, healthy birds then on the plant were saved, incubated in sterile incubators, the chicks taken from the incubators in sterile baskets to a tract of land in North Amherst upon which no birds had been kept for years, and there raised under the direction of persons in no way in contact with the infected College plant. By this method about 2,700 healthy young birds were raised to take the place of the old, diseased flock that had been kept at the College plant.

As soon as all birds on the College plant had been disposed of early in July, a vigorous clean-up campaign was started. All houses and yards were cleaned, fences removed, yards plowed, etc. After the rough cleaning had been done, every building, with equipment, was thoroughly disinfected with a strong solution of a coal-tar disinfectant applied by means of a power spray pump, which made it possible to drive the solu-

tion into the smallest cracks and crevices. After plowing and harrowing, the yards were heavily limed, leveled and seeded. In those buildings where disinfectant solutions could not be used satisfactorily, sulfur fumes were used in combination with the liquid disinfectant to insure a perfect destruction of all infectious matter.

Early in October the clean-up work of the Veterinary Department having been completed, an inspection of the poultry plant was made by the farm committee of the Board of Trustees, who reported everything in a satisfactory condition. At this writing it is particularly gratifying to receive from Dr. Goodale, who is in immediate charge of the flock at the College poultry plant, the following: —

> It is a pleasure to know that we have, thus far, no infectious diseases. Our mortality, aside from purely physical causes, has been practically nothing.

BULLETIN No. 195.

DEPARTMENT OF BOTANY.

TOBACCO INVESTIGATIONS.

PROGRESS REPORT, INCLUDING MISCELLANEOUS OBSERVATIONS ON TOBACCO.

BY G. H. CHAPMAN.

Introduction.

The production of cigar leaf tobacco has been for many years a very important agricultural industry in the Connecticut Valley, and in 1916 there were approximately 9,000 acres under cultivation in the Massachusetts section alone. By far the greater part of this was of the variety known as Havana, but some Broadleaf, shaded Cuban, and Sumatra were also grown. The value of the crop was estimated at, roughly, $3,600,000.

It can be seen from the above that the gross income derived from the growing of tobacco in Massachusetts is very large, and must of necessity be a very important factor in the regional community prosperity.

The successful raising, curing, and packing of tobacco is, as is well known, an art in itself, and very difficult of uniform attainment. The tobacco plant is very susceptible to comparatively slight changes of environment, and to grow tobacco successfully for a long period of years on the same soil requires, of necessity, extremely close observation and skill in agricultural practices. That success does not always attend the growers is more or less evidenced by the report alleging that the average yield in Massachusetts is falling off, and also that the percentage of wrapper leaves in crops is decreasing.

The season of 1915 was particularly unfavorable for the development of tobacco, and, as a consequence, the growers requested that experimental work be carried on by the station relative to ascertaining the fundamental underlying cause or causes of the apparent deterioration of the crop. No funds were available to carry on this work until the late summer of 1916, when an appropriation was made for this purpose. The collection of data relative to crop conditions and other phases of agricul-

tural practice was commenced at this time with a view to outlining experimental field and laboratory work for the ensuing years.

It has seemed unwise to make a yearly report until the data of at least two years were available, and therefore the present report includes the preliminary observations made during the latter part of 1916, and a discussion of the results obtained from the different lines of experiment suggested by these findings. These will be treated under their proper headings in the body of the report, with a general summary of conclusions and recommendations following.

Preliminary work was undertaken so late in the season that it was impossible to collect first-hand data on seed-bed conditions. The work was therefore confined to making a survey of the crop and soils in general, with a view to obtaining accurate information regarding the situation. After compiling and correlating these data it was planned to establish in 1917 experimental plots in different sections, and by various treatments endeavor to produce a favorable tobacco condition in the so-called "sick" soils. The problem is not primarily one of soil fertility, as it is generally true that crops other than tobacco — such as onions, corn, etc. — make a very luxuriant growth on the "sick" tobacco soils, and this often without additional fertilization.

Investigations necessary.

From the results of our study of 1916 conditions, it was apparent that the questions involved required the undertaking of several lines of investigation in order to reach a satisfactory solution. Undoubtedly it may be found necessary to change or modify the various experiments as time passes, but there are certain questions which should be answered as soon as possible. Among the more important are the following: —

1. Is the average yield of tobacco gradually falling off from year to year, generally, throughout the valley?

2. Is the quality of the tobacco produced inferior to what has been the average quality?

3. Has the weather factor been a primary controlling factor in production, — especially in later years, — and what limits are permissible for profitable production? (This hardly seems necessary of demonstration.)

4. Is there a correlation between weather factors and diseases, such as root-rots caused by *Thielavia basicola* and other organisms?

5. Aside from the general decrease in crops in 1915–16, and to a lesser extent in 1917, what is the cause of the soil "sickness" on some fields, or parts of fields? Is it due to a parasite, or is it due to improper fertilization and cultural methods?

6. Is there any correlation between the fertilization methods and soil treatment, and the activity of the root-destroying organisms? In other words, have we got some of our fields into a condition which favors the

development of the disease-producing organisms, and which, at the same time, is unfavorable for the optimum growth of the tobacco?

7. What corrective fertilization and cultural methods may best be employed in the latter instance?

Briefly, the investigation may be divided into three main parts, as follows: —

1. *A study of the meteorological factors as related to the growth of tobacco.*
2. *A biochemical study of the soils of normal and "sick" fields, including fertilization experiments.*
3. *A study of the micro-flora and micro-fauna of normal and "sick" soils, including those forms found to be parasitic on tobacco.*

Is the Tobacco Crop actually failing?

It has been repeatedly stated that the average yield per acre of tobacco in Massachusetts is decreasing gradually, and has been so doing for the past ten or fifteen years. This, if true, would be very alarming, and would indicate a widely distributed, serious situation due to parasites or to improper cultural methods. The following data will show the situation as it really is. Some years ago the United States Department of Agriculture, through its Bureau of Statistics, began reporting various data regarding the principal crops of the United States. Tobacco was included, and the following data have been secured from the annual figures as published in the various Year Books of the Department.

The average yield of tobacco in Massachusetts from 1870 to 1910 is calculated as 1,580 pounds per acre. At present this would seem a rather high figure, as the acreage devoted to shade-grown Cuban has increased in the past ten years, until in 1918 approximately 1,100 acres were devoted to this crop out of a total acreage of some 9,000. The yield of shade tobacco is much less than field-grown, not averaging over 1,000 pounds per acre, and this low yield of the Massachusetts acreage would of necessity, reduce the average yield, if yield is calculated on total acreage. However, as no other figures are available, the above-mentioned average is taken for the period 1870 to 1910.

The yield per acre is plotted in Fig. 1, and is self-explanatory. The straight broken line indicates the average yield. The heavy black line represents the seasonal variation.

It is at once apparent that until the disastrous seasons of 1915 and 1916 the yield over a period of fourteen years was, with four exceptions, well above the average, and two of these years, 1902 and 1913, were only slightly below the average. If we average the yields as plotted for the eighteen years we find that, even with the exceedingly low yield of 1915 included, the average yield for the period has been 20 pounds above the average yield calculated for the forty-year period of 1870–1910, — namely, 1,580 pounds.

It is only too true that the figures available are based on estimates which are, perhaps, somewhat at variance with the actual facts; but in

any case the factor of error would be identical from year to year, and the general comparative results may be considered trustworthy.

The yield has fallen off seriously only in 1915, and to a lesser extent in 1917; but in spite of these low yields the average yield of tobacco in the period 1900–18 has been above the average of the forty-year period 1870–1910.

There is no justification for the statement that the yield of tobacco on Massachusetts fields has been decreasing *gradually* for the past ten years; but, on the contrary, in spite of the exceedingly low yield of 1915

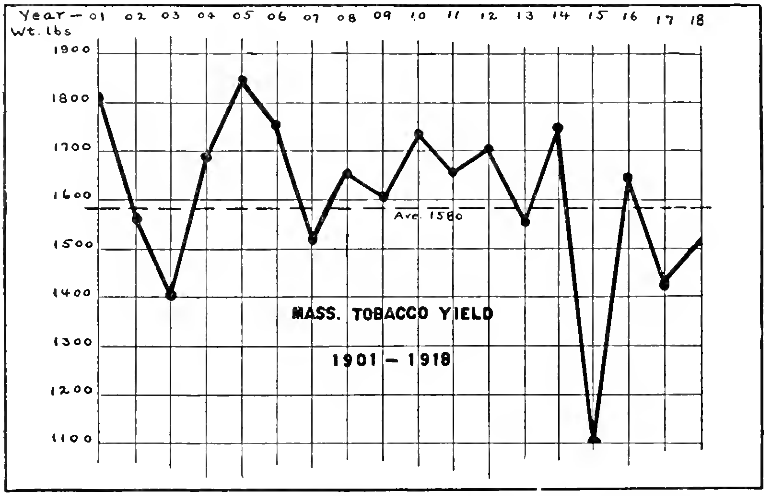


Fig. 1.—Average yield per acre of Massachusetts tobacco from 1901 to 1918, inclusive. The horizontal dash line indicates the average yield from 1870 to 1910.

the calculated average is being maintained. If, however, we consider only the yields of 1915, 1916, 1917, and 1918, it is true that a yield below the average will be found; but some of these seasons have been admittedly unfavorable for tobacco, from the meteorological standpoint, and high yields could not be expected. Also it is incorrect, or at least misleading, to base a statement of *general* yield on so few years' data. The same conditions meteorologically have in the past produced almost identical results, as will later be pointed out.

Weather Factor in Tobacco Growing.

In general, it may be stated that the first half or more of the growing season of 1916 was decidedly unfavorable to the growth of tobacco. Conditions improved from shortly after mid-season until the crop was harvested, and a rapid and apparently satisfactory growth was made. The leaf was of good size and color, but although seemingly in good condition, was inclined — as later developments proved — to run rather light in

weight. There was a tendency on the part of many growers, resulting perhaps from their experiences in 1915, to harvest the crop before it was mature; whereas, as a matter of fact, the leaf matured in general rather late in 1916. This factor undoubtedly influenced somewhat the character and weight of the leaf.

It is a self-evident fact that rainfall, temperature, sunlight, humidity, etc., are very important factors in the normal growth of any crop, and perhaps exert a greater influence than usual in the case of tobacco, which is particularly sensitive to slight environmental changes. The season of

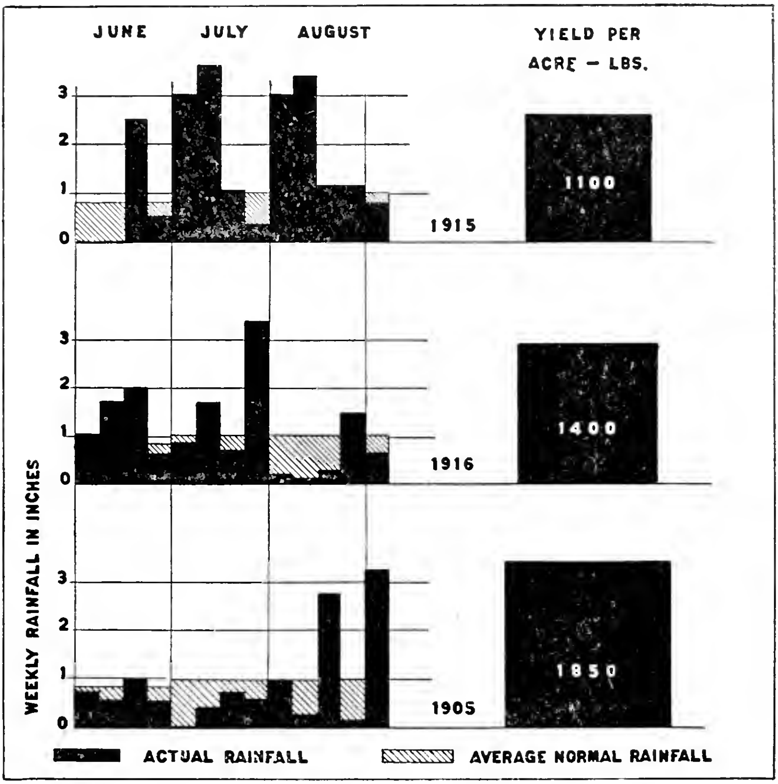


FIG. 2.—Comparison of actual rainfall and yield with normal rainfall for 1915, 1916, and 1905, a so-called "dry" year.

1915 was one of very heavy rainfall, as was that of 1916; therefore, as a means of comparison of conditions, the rainfall of 1916 has been plotted with that of 1915, and with a so-called "dry" year in which the crop was of good weight and quality. Fig. 2 shows the rainfall in inches week by week from June 1 to September 1, the variation from the normal, and the yield for each of the years. The correlation of excessive moisture and low yield is certainly very marked; also the converse: subnormal rainfall, well distributed, with a high yield.

It will be noted that the season of 1916, as a whole, was very wet, with excessive rainfall occurring during the first two-thirds of the growing period. The season of 1915, which was so disastrous, was even more wet; but a reversal of the 1916 conditions is found, most of the rainfall occurring during the last two-thirds or half of the season, when the crop was going through its period of greatest growth, and maturing. The season of 1905, while rather dry, produced many fine crops of tobacco (although they were later damaged by pole sweat), and it will be noted that the rainfall was low; in fact, the precipitation was below normal in many of the weeks and, as a whole, the season would be considered a droughty one. The fact that the last week or two were very wet, and consequently interfered somewhat with harvesting, does not in any way lessen the importance of the statement that the crop was very large. The quality, however, was slightly lowered.

There is no question but that the excessive precipitation of the two seasons first mentioned reduced the weight and quality of the crop; but its general effect was much less in 1916, when most of the excessive rains occurred in the first half of the growing season. These checked early growth in the field, but a subsequent return to normal, or thereabouts, in August allowed of a rapid development in the last few weeks, although, in spite of the favorable conditions, the crop was late in maturing. The excessive rainfalls of 1915 and 1916 have, in all probability, been an important factor also in intensifying the effects produced on the crop by the various forms of soil "sickness."

To illustrate: It was observed that on fields known to be badly infested with the root-rot fungus (*Thielavia basicola* Zopf.) the percentage of plants infected sufficiently to check growth was much greater than usual in 1915 and 1916. The apparent leaching out of certain plant foods, especially the more soluble forms of nitrogen, was also observable, as indicated by the character of growth on some fields. Mention will be made of a few interesting observations on this point later in the report.

The theoretical benefit which might be derived from the leaching out of the accumulation of soluble salines — which Haskins[1] found to be excessive (as compared with soils producing normal crops) in certain spots and fields producing unthrifty plants — was apparently observable in some cases and not in others. It is unfortunate that determinations of the change in amounts of these salines present in soils which had been previously examined were not made, but lack of time prevented this.

It is a well-recognized fact that rainfall, soil-moisture, and temperature all play an important rôle in the making of quality of tobacco, and it is also true that, as a rule, the finest quality of cigar leaf is raised on light soils which carry relatively only a small percentage of moisture, say from 7 to 15 per cent. Aside from quality alone, in seasons with excessive rains there is always a falling off in the crop, particularly as regards weight.

A study of the rainfall, relative humidity, hours of sunshine, and

[1] Haskins, H. D. Twenty-fourth annual report, Mass. Agr. Exp. Sta. (January, 1912), p. 35.

temperatures during the main growing season as compared with the weight of the crop has therefore been made. The data as to average yield and yearly production in Massachusetts were obtained from the various Year Books of the Department of Agriculture. These figures are the only ones available, and it is believed by the writer that in most instances, at least, they are reliable. The meteorological data are taken from the records of the Massachusetts Agricultural College observatory, and are fairly representative of conditions in this section of the valley. The observatory is located within two or three miles of the center of the Massachusetts tobacco area around Hatfield. Of course, observations taken only a few miles distant would differ somewhat, but only in minor details, and it is believed that we are fully justified in using these observatory records. No data are available as to seasonal differences in water content of the different soil types in the tobacco region in Massachusetts. The quality of the crop in the different years was also difficult to ascertain, as here it was necessary to depend largely on the grower's or packer's memory for data, and they often were unable to recollect a crop for a given year with sufficient accuracy to make a comparison reliable. Therefore quality has not been plotted.

The average yearly yield per acre in Massachusetts is given in Table I for the period from 1901 to 1918, inclusive, together with the average yield from 1870 to 1910.

TABLE I. — *Average Yield of Tobacco per Acre in Massachusetts, 1901–18.*

YEAR.	Yield (Pounds).	YEAR.	Yield (Pounds).
1901,	1,810	1911,	1,650
1902,	1,560	1912,	1,700
1903,	1,400	1913,	1,550
1904,	1,690	1914,	1,750
1905,	1,850	1915,	1,100
1906,	1,750	1916,	1,600[1]
1907,	1,525		1,400[2]
1908,	1,650	1917,	1,430
1909,	1,600	1918,	1,520
1910,	1,730	Average yield, 1870 to 1910,	1,580

[1] United States. [2] Massachusetts Agricultural College.

It will be seen that there is a marked variation in yield from year to year. The yield for 1916 as given by the United States Department of Agriculture (1,660 pounds) is much greater than the one estimated by the writer (1,400 pounds). This is probably due to the fact that the latter figures were obtained in part from the packing houses.

Fig. 1 is a graphic representation of the variation indicated by the above figures.

There was, unquestionably, a great reduction in yield in 1915, 1916, and 1917. *Can we look to a specific soil trouble, pathogen, or method of culture to account for this sudden and marked* GENERAL *decrease in yield?* It is hardly conceivable. A careful study of the yield in comparison with the meteorological conditions, however, does furnish us with important data, at least partially explanatory of the same. A study of Plates I and II (A and B), it is believed, will convince the most skeptical that the weather conditions during any given growing season determine to a great extent the yield, and that the *general* reduction in 1915 and 1916, as well as in other bad years, must be primarily attributed to these factors.

In these plates the normal for this locality is represented as the straight horizontal line or mean, and designated as (0). The variations of any given period — in this case, monthly — above or below normal are represented in black by the difference between the normal and that of any given month. Variations above normal are represented above the line, and below normal, below the line. Sunshine variation is given in hours, temperature variation in degrees Fahrenheit (F°), relative humidity in percentage, rainfall in inches, and yield in pounds per acre. Each season is divided into three parts, corresponding to the three principal months during which maximum growth occurs, — June, July, and August.

Studying these tables it is found that there is a rather close correlation between the various factors and the yield. Rainfall is, in Massachusetts, probably the most important factor bearing on the yield, followed closely by temperature and sunshine. The relative humidity apparently is not of such importance, so far as the actual yield is concerned. Calling attention to only a few of the more important differences will suffice.

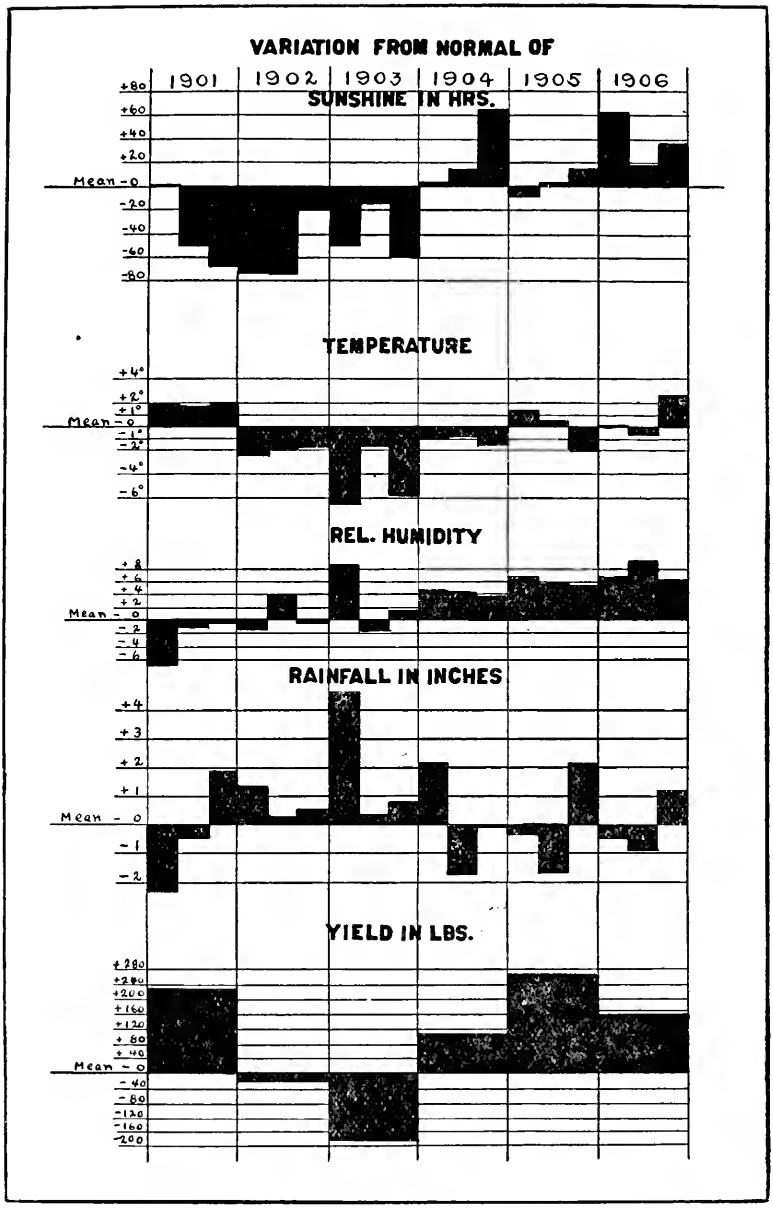
1915. — Sunshine slightly above normal in June, much below normal in July and August; temperature, 1.5–2.0° below normal for the entire growing season; relative humidity above normal except in June; rainfall practically normal in June, but from 4 to 5 inches in excess of normal during July and August; yield, 480 pounds below normal!

1916. — Here we have the reversal of conditions before mentioned: sunshine much below normal in June and July, above normal in August; temperature below normal for June, but above in July and August; rainfall excessive except in August, when it was 2 inches less than normal; yield better than in 1915, but still 180 pounds below normal.

1917. — Here we have a partial return to more normal conditions, but still somewhat abnormal; yield, 50+ pounds below normal for stalk tobacco.

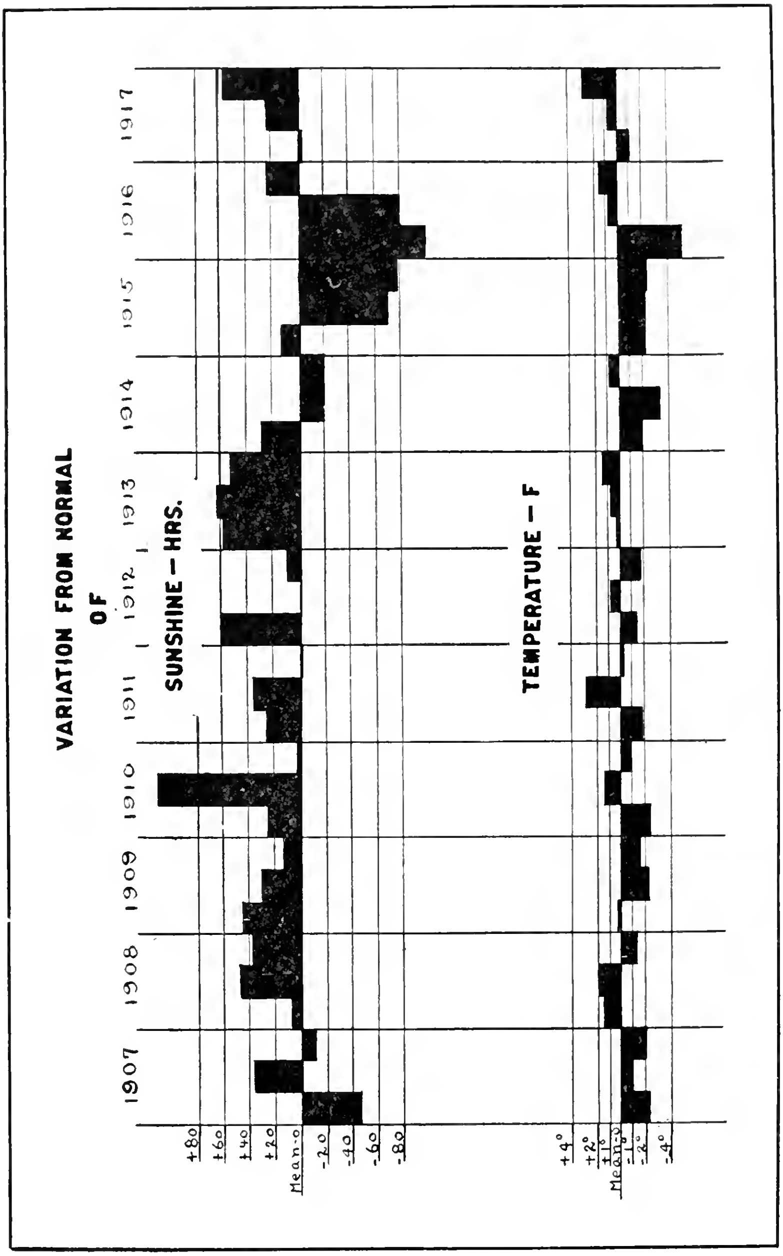
Going back still further it is possible to find analogous conditions in other years. It is safe to conclude that if there is excessive rainfall during the growing season, combined with low average temperature during the first half of the growing season particularly, the yield per acre will be small.

PLATE I.



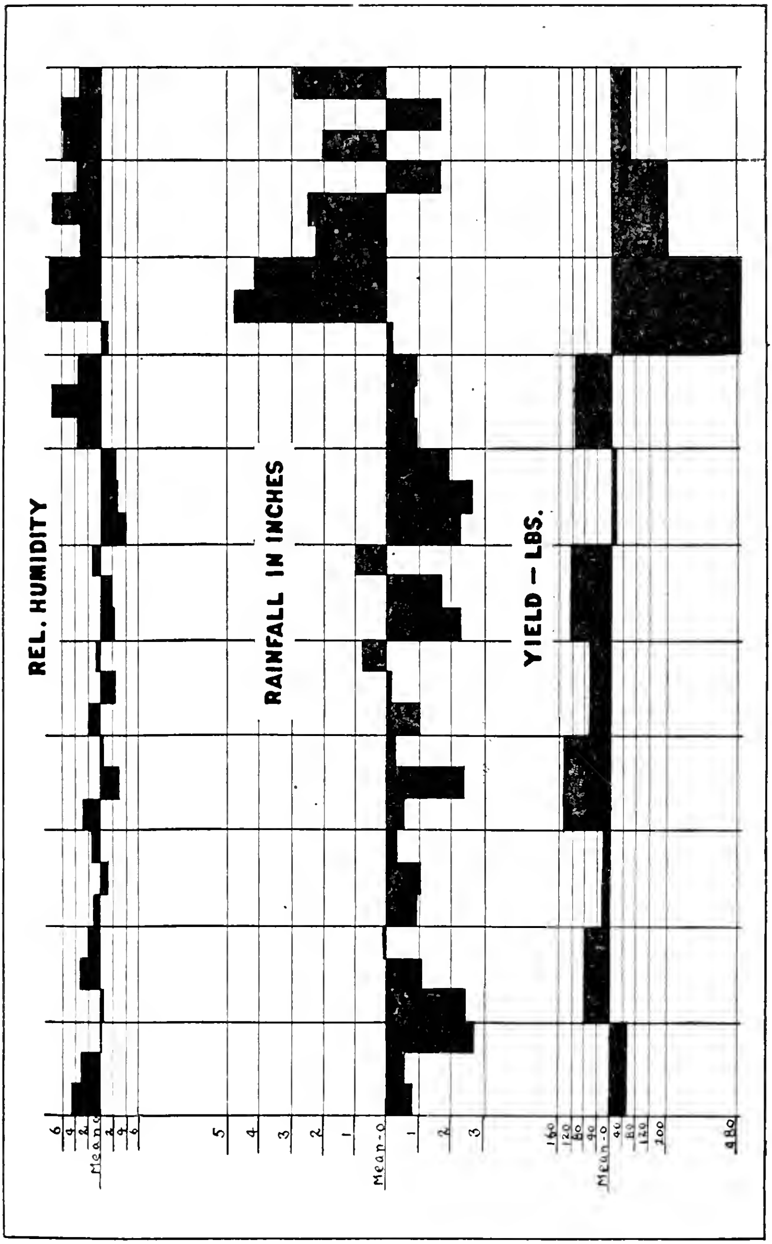
Variation from normal of sunshine, temperature, relative humidity, rainfall and yield, 1901-06, inclusive

PLATE II A.



Variation from normal of sunshine and temperature, 1907–17, inclusive.

PLATE II B.



Variation from normal of relative humidity, rainfall and yield, 1907-17.

Excessive drought, combined with low or high temperatures, will also reduce the yield, but not usually to so great an extent as in the case of excessive rainfall. Good examples of the effects of drought on yield are to be found in 1907, and to a lesser extent in 1913.

Subnormal rainfall with subnormal temperatures does not reduce the yield to any great extent, providing they are not excessive (see 1909, 1910, 1912). The quality of the leaf is apt to suffer somewhat, however, in such cases.

A careful examination of the data leads us to the conclusion that for the development of our best crops we must have a season with normal or slightly subnormal rainfall, fairly well distributed, together with practically normal or supernormal temperatures.

Another factor of great importance is the distribution of the rainfall. For the best results the rainfall should be more or less evenly distributed over the growing period, not all in any one month or on a very few days of the month. The season of 1917 shows very well the effects of an unequal distribution of rainfall which, while averaging little above normal, reduced the yield. Here a very wet June, followed by a very dry July, brought the crop along to the danger point, and then the excessive rainfall of August, while helping growth, did not permit of a normal maturity, and as a result we get a subnormal yield.

As a result of the examination of these plates we may state that, in general, *rainfall is the major limiting factor of growth (and this necessarily includes soil moisture), together with temperature.*

Excessive seasonal rainfall is invariably followed by a reduction in yield independent of temperature.

Subnormal rainfall, when accompanied by temperatures excessively above normal, reduces the yield.

Subnormal rainfall, when accompanied by subnormal temperatures, does not apparently reduce the yield to any extent unless the rainfall is very much below normal.

In other words, there are apparently certain well-defined limits between which we may expect to get a normal yield, or better. A total rainfall for the season of from $6\frac{1}{2}$ to 12 inches, if fairly well distributed, will give a good crop. Less than this or greater will give a yield below normal.

These conclusions are *general* and *seasonal*, and do not take into consideration other factors, such as *effect of precipitation* on soil temperature, fertilizer applied, parasitism of disease-producing organisms, type of soil, and method of culture. All these factors do play a more or less important rôle concurrently, but fundamentally rainfall and temperature are to be considered the limiting factors in production. The other factors mentioned are decidedly more local in their action, and are often possible of correction. They are what might be termed "individualistic," while the others are "communistic."

The effects, in any one season, of the rainfall and temperature as related to growth also make a very interesting study, and any one interested

would do well to read Bulletin No. 39 of the Bureau of Soils, United States Department of Agriculture, in which is reported a season's study of these factors at Tarriffville, Conn. It would be out of place to detail them here.

In conclusion, it might be well to emphasize again that the *general* reduction of crop yield per acre is invariably associated with the seasonal rainfall and temperature, and not to any "running out" of the land (which was amply shown by the fact that the 1918 crop, according to returns, was much improved over those of 1915 and 1916, and was practically normal in spite of the July drought), due, primarily, to a specific widespread soil trouble.

This conclusion does not in the least minimize the fact that in many localities there is undoubtedly trouble due to improper fertilization, methods of culture, and disease-producing organisms; but these are *specific* problems, and not susceptible to *general* analytical consideration except in the group to which they belong.

They *may* assume major importance in seasons presenting abnormal meteorological conditions, and in such seasons are often held responsible for all reductions in yield. This should not be done, however.

Soil Relations.

During the season of 1916 many fields were observed where the unfavorable condition of the crop could not be accounted for by the presence of disease. On these fields the leaf was apparently normal in size or, in some areas, small and undeveloped; but it was thin and papery, and did not show the weight and quality of normal leaf grown on the same type of soil. In these cases not attributable to parasitic organisms we must look to an unbalanced physiological relationship between the plant and the soil, and this, naturally, first involves a study of the soil composition, reaction, and methods of fertilization.

Many theories have been advanced to explain this particular type of non-productiveness of tobacco soils, such as overfertilization, under fertilization, excess of soluble salines, toxic substances formed in the soil by the interaction of certain fertilizing constituents, injurious fertilizer constituents, the accumulation in the soil of toxic excretions from the roots of the tobacco plant, lack of potash, and a variety of other causes any one or more of which may possibly, under certain conditions, furnish the correct explanation. In general, however, it has been found difficult to ascribe the condition of the crop on such fields to any one factor with any degree of certainty, and it would appear that careful investigation is necessary to clear up some of these questions. In all probability no single factor is responsible.

It has generally been supposed that tobacco thrives best on a soil approaching neutrality, but our observations lead us to believe that this may not be entirely true, and that, possibly, some of our soils are too

nearly neutral for the best development of tobacco. This seems to be particularly true where large quantities of lime have been applied to soils. The "good" tobacco soils examined showed a comparatively high "lime requirement," as determined by the Jones' method, using Haskins' factor for Massachusetts soils (4.46 instead of 1.8).

By the term "lime requirement," as used in this connection, is meant the amount of lime in the form of calcium oxide, CaO, it would be necessary to add to the soil to exactly neutralize it, *i.e.*, make it neither acid nor alkaline. It is not implied that the amounts of lime indicated in any given instance would benefit the tobacco crop.

The writer believes that, as a measure of the actual "lime requirement" or acidity of soils, none of the present methods of determination are satisfactory, and do not, in many cases, even approximate the true value sought; but when used as a comparative indicator for laboratory purposes in the examination of a series of soils they may be applied with advantage. In Table II will be found the "lime requirement" of some typical fields examined, together with comments on the crop, type of soil, etc.

TABLE II. — *Classification of Certain Soils according to "Lime Requirement," together with Data on Crop Condition, etc.*[1]

Group I.

Sample No.	Acidity indicated by CaO Requirement (Pounds).	Crop Condition.	Root-rot Infection.	Years in Tobacco.	Limed.
07	1,200	Very poor,	No,[2]	-	Yes.
03	2,700	Very poor,	No,	-	Heavily.
8	3,000	Poor,	Light,	-	Yes.

Group II.

12	4,500	Poor,	Light,	-	Yes.
16	4,500	Poor; fair,	Light,	-	Heavily.
18	6,000	Fair,	Light; medium,	-	Heavily.
2	6,500	Very poor,	Very heavy,	6	Yes.
6	6,500	Thin; large growth,	Heavy,	40	Occasionally.
4	7,000	Poor; patchy,	Very heavy,	30-40	Occasionally.
14	8,000	Fair,	Light,	-	Little.
22	8,000	Very good,	Trace,	-	No.

[1] The data given in this table represent only a part of the total collected, but are typical of conditions in general.

[2] "No" indicates that no root-rot was found on roots of plants examined. It is entirely probable that a very extended examination might in all cases reveal a slight amount.

TABLE II. — *Classification of Certain Soils according to "Lime Requirements," together with Data on Crop Condition, etc.* — Concluded.

Group III.

SAMPLE No.	Acidity indicated by CaO Requirement (Pounds).	Crop Condition.	Root-rot Infection.	Years in Tobacco.	Limed.
20	8,800	Good, ...	No, ...	-	No
011	8,900	Excellent, . .	Trace, ...	-	- -
A21	9,400	Very good, . .	No, ...	4	No.
24	9,900	Good, ...	No, ...	-	- -
30	10,500	Good, ...	Trace, ...	-	No.
26	13,500	Very good, . .	No, ...	2	No.
V17	15,500	A virgin soil ready for tobacco.			

The results are significant, and indicate that tobacco is making a better growth on soils which, with our method of acidity measurement, would be classed as rather acid. Until further investigation is made it would be unwise to emphasize this point unduly. Apropos of this, the general observations of Beals[1] on limed and unlimed areas substantiate, in a measure, these experimental findings. He found that out of 58 growers who made reports 43 had used lime more or less continuously, and most of these reported soil "sickness," while among those not using lime, only one case of soil "sickness" was reported.

A Study of the Reaction of Normal and "Sick" Soils as indicated by the "Lime Requirement."

In the past three years over 300 determinations of the so-called "lime requirement" of soils of all types used for tobacco have been made, as well as some of virgin soil broken for the first time for tobacco. The samples collected in different years were taken at approximately the same week or month, as the case might be, and as nearly as possible under similar conditions. In Table III there are arranged in groups the values obtained, together with brief notes on the condition of the crop during the season in which the samples were taken. It has not been attempted to include in this table, individually, all the soils examined, as this would be too cumbersome. The theoretical "lime requirement" is given in terms of CaO, and not as limestone or other commercial forms of lime.

[1] Beals, C. In report of thirty-third annual meeting of New England Tobacco Growers' Association. Feb. 16, 1916, p. 25.

TABLE III. — *Tobacco Soils arranged in Groups according to "Lime Requirement," with General Notes on Crop Condition.*

	Number of Soils examined falling in Group.	Condition of Crop.	Root Diseases Present.
Group I: — 0-3,000 pounds CaO requirement.	21	Poor; fair, . .	None-slight.
Group II: — 3,000-8,000 pounds CaO requirement.	137	Poor; excellent (better as the higher limit is approached).	None-very heavy (usually present).
Group III: — 8,000-15,000 pounds CaO requirement.	29	Good; excellent, . .	None-slight (unusual).

The results given in this table apparently indicate that tobacco is making a better growth on soils which are rather more "acid" than we have been in the habit of believing to be best for tobacco. As a matter of fact, the soils which show the least acidity are those which have had in the past large and more or less consistent applications of lime, or those which have been planted to tobacco for a long period of time. Whether or not these soils which seem to be so "acid" actually are, is an open question. In all the methods of acidity determination used, we measure the amount of acidity and not the intensity, and it is being found that a determination of the concentration of the hydrogen ion gives us, often, different results.[1] These results are important, and bring before us the question of lime (for we reduce the acidity of our soils by liming or by certain systems of fertilization) and its use on tobacco soils. Do they indicate that we have been liming too much, and that if we keep off lime entirely for a time we will eradicate much of the trouble? This cannot be stated absolutely as a general proposition in the light of work carried on so far, but it can be positively stated that we have found many instances where lime, especially in active form, has been applied to soils with the result that in from two to three years the crop has been reduced considerably. This is particularly noticeable where lime has been dumped and then later spread. The areas on which the lime was dumped became very unproductive, and we are therefore justified in stating that it would be advisable to withhold lime from fields which have been in tobacco for some time, especially from lighter soils where the supply of organic matter is small. Apropos of the advisability of adding lime to tobacco soils, especially light soils, it should be noted that

[1] A study of the hydrogen ion concentration in our tobacco soils is in progress and nearing completion. This study is to include a comparison of results obtained by this method with those of the present report, and a discussion of the practical interpretation of the same. This paper, which will of necessity be more or less technical in character, will be published separately.

some of the fertilizers used are alkaline, and that most of the brands contain in the neighborhood of 200 pounds of some form of lime added for various purposes.

The question as to whether the addition of large quantities of lime is necessary on our soils for the best development of tobacco — and its effect on the burn, ash, etc. — is still open to investigation. It depends to a certain extent on the type of soil. Recent investigations by the Dutch East Indies station have shown that the addition of lime had little effect on these factors. On the contrary, in some cases where the burn was injured there was a beneficial effect on the quality and color. Other experiments showed opposite results, and in general no particularly good effects were observed.

There is no question but what some lime is necessary for the best development of the tobacco plant, but a small application every few years seems to be preferable to a heavy application two or three years in succession. The mechanical composition of the particular soil to which the lime is to be applied should also be carefully considered.

There is another factor, connected with the liming of our fields, aside from that of the direct injurious effect of lime on the growth of tobacco as a result of the changing of soil reaction toward neutrality. Certain of our experiments have shown that the fungus *Thielavia basicola*, which causes root-rot, is very susceptible to acids, and we have found that it is very difficult for the fungus to thrive on very acid media. On the other hand, on media approaching neutrality the fungus develops rather better and makes a far more rapid growth. We are at present testing out in the laboratory different concentrations of acids and different acids, together with soil extracts, to determine if there is any difference in their reaction on the fungus.

These data regarding Thielavia root-rot substantiate the findings of Briggs,[1] who in 1908 reported results on the intensity of root-rot infection on tobacco in alkaline and acid soils, and who also recommended the stopping of lime applications on infected fields.

Referring again to the preceding table it might be stated that the roots of plants on the various soils which were analyzed were examined for Thielavia root-rot infection, and some interesting data were secured. It was found that in the soils of Group I, as it has been called for the sake of convenience, — that is, those soils which showed a "lime requirement" of from 0 to 3,000 pounds CaO requirement, — the crop was very poor; but there was little or no Thielavia root-rot evident. On the soils which I have designated as Group II, the crop was poor and patchy, or good, and on many plants the Thielavia root-rot was present in sufficient amount to cause a marked loss of root-feeding area. These soils all fell within a range of CaO requirement of from 3,000 pounds to 8,000 pounds. In Group III were placed all the soils showing a "lime require-

[1] Briggs, W. The Field Treatment of Tobacco Root-rot. U. S. D. A., B. P. I., Circ. No. 7, 1908.

ment" above 8,000 pounds CaO, the crops of which were normal as far as growth was concerned, and many of them were very fine. In this group we find the acidity as measured in terms of the CaO requirement running as high as 13,500 pounds per acre. The highest value closely approaches the acidity of our virgin soils, such as are used when new tobacco plantations are established. Two of these virgin soils gave a "lime requirement" of over 15,000 pounds per acre.

From the preceding we can see that the situation with respect to liming is still further complicated. We have, on the one hand, the lime question and its effects on the growth of tobacco, pure and simple, and on the other, the effect of the soil reaction on the fungus which causes the Thielavia root-rot. If we lime continually and excessively land on which this root-rot is established, we are constantly getting it into a more nearly neutral condition, and hence into a more favorable condition for the development of the root-rot. In the end we will have a soil in which every year, irrespective of other factors favorable or unfavorable to the growth of the fungus, it will be able to develop vigorously and do great damage. In such cases soil reaction (changed by liming) should be looked upon as the primary cause of the trouble, and the presence of root-rot as secondary to this.

We find that this root-rot is not present to any great extent on soils showing a very low "lime requirement," which indicates that the soil is too alkaline for the development of the fungus, and also too alkaline for tobacco to make a satisfactory growth. At any rate, in this group (soils showing 0–3,000 pounds CaO requirement) the fungus is rarely found, though usually the crop of tobacco is very light and of poor quality. In the second group we find a large number of soils showing from 3,000–8,000 pounds CaO requirement, and it is to be observed that the Thielavia root-rot is present in a large number of fields. On these soils the crop varies from year to year, and in many cases is not of a satisfactory nature. On soils of this character in some years, however, good crops are produced, so we cannot here lay the damage to the lime alone, but must look to other additional factors.

In the third group we have soils which are acid and which show a high "lime requirement," — 8,000 pounds CaO and up, — but which are practically free from root-rot, and these soils are in practically all cases producing a good crop of tobacco. Does this not seem to indicate that the relationship between liming and Thielavia root-rot just discussed is a potent factor in many cases in the development of our troubles? There are, however, other factors to be taken into consideration, and in some cases these are of great importance also.

There is this fact patent, that on new land the tobacco always makes a good growth, although the quality of the leaf may not be all we desire. In these times, when the first consideration of the grower is apparently to get weight and let the quality come later, this is important, at least to the grower who has new land at his disposal. Most of the growers,

however, have not new land that is suitable for tobacco, and cannot extend their activities in this manner, so of necessity they must confine their attention to keeping their tobacco fields in good tobacco condition by careful methods of fertilization.

Mere weight should not be the aim of the grower, as eventually this will lower the standard of Massachusetts tobacco. It is a well-recognized fact that heavy, rank tobacco is not, year in and year out, in demand by the manufacturers, and the aim should be to produce a fair weight of tobacco which has quality. A satisfactory price must be obtained for such a product, and it is due to the low price paid, more than to any other single factor, that the growers are striving to increase the weight of the crop. The cost of production is so great in Massachusetts that to secure adequate returns we must continue to grow a wrapper crop of good quality.

To return to the question of soil reaction and the practice of liming, it might be well to emphasize again the data collected by Mr. Beals of this station in 1914 (*loc. cit.*).

It is true that some growers have been using lime more or less continuously for some time, and are still producing excellent crops of tobacco, but this is the exception, and other factors — such as soil composition, organic matter supplied, etc. — are more or less responsible for the success of these men.

Humus or Organic Matter Content of Massachusetts Tobacco Soils.

The soils reported in Table II were analyzed for humus content by the method of the Association of Official Agricultural Chemists [1] as modified by Rather,[2] and a somewhat wide divergence in humus content was found, as might be expected. There were found some indications of a relationship between humus content and crop condition, as well as "lime requirement." Low humus content was more often associated with low acidity and poor crop condition. It may be safely stated that many of the soils producing poor crops are deficient in humus. Usually the presence of an optimum amount of humus or organic matter in a soil is considered an essential to crop production, but whether the quality of the leaf is injured or not by large amounts of humus in the case of tobacco is of importance. Growth and weight, without quality, are not to be desired. The question of the addition of humus to soils, found markedly deficient in this substance, is one which will bear investigation. Where it is found necessary to supply humus, we have the choice of crop rotation or cover-cropping and manuring, and, as most growers feel that they cannot practice extensive rotation with profit, cover-cropping and manuring would appear to be the only satisfactory solution of the matter so far as the question of humus is concerned. Whether, as some firmly

[1] Official and Provisional Methods of Analysis. U. S. D. A., Bureau of Chemistry, Bulletin No. 107.

[2] Rather, J. B. Texas Bulletin No. 139. May, 1911, pp. 10-15.

believe, to restore the "sick" soils it will be necessary to rotate on a three or four year basis, is an open question, but one which should be seriously considered by those whose land is in very poor condition. It is to be hoped, however, that some treatment will be discovered which will render this unnecessary.

Continued examination of normal and "sick" soils during 1917 and 1918 has served to substantiate the findings of the first year. Almost invariably there has been found to be a relationship between the organic matter content of a given soil and the development of the crop. This was especially true in the case of old fields which had been heavily limed, and fertilized for years with "chemical" fertilizers. These same fields, as a rule, had had no addition of organic matter, except such as came from the cottonseed applied, or from the stalks plowed under.

Our light and heavy soils, of course, vary widely in the content of organic matter when in a virgin condition, and, as a rule, the light types are the first to be depleted of their organic matter. These also are the soils which contain normally the smallest amounts of organic matter. Continued liming depletes the organic matter very quickly, and in this practice we have undoubtedly exceeded the limits to which we may go and maintain a favorable amount of humus in the soil.

Some of the soils show a very low humus content, — even less than half of 1 per cent, — and in some cases, even on the heavier types of soils, we found less than 2 per cent. The natural organic matter or humus content of our tobacco soils varies from about $1\frac{1}{2}$ to 5 per cent or more, depending on the type of soil. It can be plainly seen that there is certainly a deficiency in many cases, and this should be remedied as soon as possible. Very few of the soils examined contained what would be considered the normal amount of humus for their type.

Organic matter is a very important factor in any soil, and particularly tobacco soils which are, in this section, cropped for years without any rest or rotation. Sufficient attention has not been paid to keeping up the supply of organic matter in the soils.

Organic matter affects the soil in many ways, both physically and chemically, and might almost be called a "soil regulator." Physically, it lightens heavier soils and binds lighter soils together and tends to make them loamy. It also increases the moisture-holding capacity enormously, and thus acts in a beneficial manner. Chemically, it adds to the plant food of the soil, as it contains the elements required by plants for food. Haskins' experiments at this station, in which he applied varying amounts of peat to some "sick" fields, showed very plainly that the peat exercised a beneficial effect on the growth of tobacco. These effects were due, probably, not only to the increase of organic matter in the soil, and the consequent action on the mechanical condition and water-holding capacity, etc., but also to the increase in soil acidity resulting from its application.

In our own experiments on "sick" soils — light and heavy — in the past two years we have shown conclusively that an application of even moderate

amounts of organic matter increases the weight of the crop to a marked extent. In these experiments the organic matter was applied in the form of peat in varying amounts, from 2 to 4 tons, on a 12 per cent moisture basis. The following tabulation will show the increase in yield resulting from the addition of organic matter, all other factors in the fertilization being the same.

TABLE IV. — *Increase in Yield resulting from Application of Peat to Certain Soils.*[1]

Plot No.	Peat Application (Tons per Acre).	Average Yield of Peat Plots (Pounds per Acre).	Average Yield of No-peat Plots (Pounds per Acre).	Per Cent. Increase.
A, F, K,	–	–	1,330	10
B, G, X,	2	1,470	–	
26, 23,	1	1,400	–	–2
1, 4, 6,	–	–	1,420	–
R, O,	2	1,570	–	10

[1] The plots received uniform fertilization aside from peat. Manure plots, and peat and acid phosphate plots, gave still higher yields.

While these data have been obtained for only two years as yet, it is believed that they are sufficiently striking to warrant tentative conclusions being made, particularly as the check plots which contained no additional organic matter were subjected to the same conditions as regards planting, cultivating, etc.

Except in certain rare cases the application of organic matter in the form of peat would be out of the question on account of the excessive cost of the material and the labor involved in carting and spreading. *How can we add organic matter to our soils at a cost sufficiently low to be practicable?*

There are several ways in which this may be done. There is added to soil a considerable amount of organic matter from stalks, cottonseed meal, manure, etc., but naturally this is not sufficient to replace the losses. Heavy manuring will apparently be sufficient sometimes, but this is an expensive form in which to apply organic matter. We cannot afford to practice any extended system of rotation, but we can supply an enormous amount of organic matter by "cover-cropping" or planting a crop in the fall after the tobacco is taken off, and plowing it under in the spring before planting.

COVER CROPS.

Cover-cropping should be practiced wherever possible, not only as a means of adding organic matter to the soil but also to prevent washing and blowing, in the case of light soils.

The choice of a cover crop depends on several factors, such as character of soil, presence of Thielavia root-rot in the field, etc. Some leguminous crop has often been advocated as a cover crop, but it is questionable if this is advisable for tobacco, as so many of the legumes (clovers, etc.) are also hosts of the Thielavia root-rot fungus, and would thus perpetuate it. *Any crop which will serve as a host for the root-rot fungus (Thielavia) should not be employed as a cover crop for tobacco.*

Rye, barley and timothy have been used in many instances with varying success, rye perhaps being most generally used up to the present time. There is one objection to rye, particularly on light lands; *i.e.*, if favorable growing weather prevails in the spring and any considerable amount of land is to be plowed, such a rapid growth of the rye top occurs that it is difficult to turn under thoroughly, and consequently it does not decay properly.

Barley is not generally used, and its use is not advocated.

Timothy has been used by some growers with good success, and from observation and trial on some soils the writer can recommend its use strongly, as it usually makes a good root growth, and does not grow so high as to be difficult of plowing under.

Although no positive data are at hand, it is believed that rye as usually planted will not furnish as much organic matter as timothy. Rye makes more top growth, but not nearly as much root growth as timothy.

According to our data, an ordinary cover crop of timothy will add to the soil over 2 tons of dry organic matter to the acre. Some figures of German investigators indicate even higher values, as much as 3 tons per acre.[1]

In addition to the direct benefit to the soil in organic matter, such a cover crop will aid in other ways. It will conserve nitrogen by preventing leaching, and will bind light soils, consequently preventing the blowing and washing which is so common in many fields.

The cost, per acre, for seed is very little, as the amount sown should usually be not over one-third bushel of good seed to the acre. The saving in nitrogen alone would more than repay the cost involved. The seed should be sown broadcast on stalk-cut fields, as soon as the tobacco is off, and on primed and shade-grown Cuban fields should be sown after the third picking at the latest.

Every tobacco field in Massachusetts should have a cover crop each year, and, so far as we can at present state, the choice should be timothy first, with rye second.

---

[1] Subsequent to the preparation of this report the Connecticut station and Hartford County Farm Bureau published analyses showing that the average amount of dry organic matter returned to the soil by a timothy cover crop amounts to 3½ tons per acre. This would be, so far as organic matter content is concerned, the equivalent of 15 tons of manure.

Tobacco Diseases.

In the Seed Bed.

It may be stated on the authority of growers that while the weather conditions in 1916 were unfavorable to a rapid and uniform development of the seedlings, the beds were relatively free from parasitic diseases. Comparatively little damping-off of seedlings was reported, but the chief trouble seems to have been the checking of plants due to cool, moist weather conditions early in the season. After setting in the field, recovery was fairly rapid in most instances, and vigorous plants were produced. Judging from field examinations later in the season there probably was less "mosaic" in the seed beds than in some years past, as the number of mosaicked plants on a large number of fields observed was less than what is considered the normal infection.

The practice of sterilizing the seed beds by means of steam or formaldehyde — preferably the former for the sake of convenience — is on the increase, and with more attention being paid to such details as high pressure, complete sterilization of all soil in the beds, etc., more uniformly favorable results should be obtained.

It is believed, however, that the practice of sterilization of the same soil in seed beds year after year may not eventually produce the results desired, as we really know very little as yet about the action of steam on the soil, and its effects may prove detrimental if long continued. Thorough sterilization, when necessary, is recommended rather than indiscriminate, careless, or partial sterilization, which only adds to the expense of the crop.

As to the presence of the root-rot fungus (*Thielavia basicola* Zopf.) in the seed beds in 1916 no positive data are at hand, as our field work was started too late to allow of any examination of the plants in the seed beds. It is fallacious, in the case of root-rot, to draw conclusions from field observations as to its probable prevalence in the seed bed, owing to the fact that the causal fungus is apparently well established in many of our fields, and has been for some time. *It becomes generally of great importance, from an economic viewpoint, only in certain years when favorable environmental conditions for its development exist.* Thorough sterilization of the seed bed will also control this fungus when it occurs there. From data at hand it is believed that many seed beds, heretofore unsuspected, are infected to a certain degree with the root-rot fungus.

In the Field.

In order of importance and frequency of occurrence the diseases affecting tobacco in Massachusetts may be classified as follows: *Thielavia root-rot*, *"mosaic"* and allied diseases, *leaf spots* of various kinds, including *"rusts,"* *damping-off* in the seed bed, *stem-canker*, root-rots apparently induced by *Fusarium* or closely related forms, root-rots apparently induced by *Rhizoctonia* forms, *albinism* and similar chlorotic conditions, *sun-scald* of

leaves, *bud-scald*, and *hollow-stalk* caused by injury and secondary invasions of organisms causing decay, and killing of plants by fertilizer applications.

Some few of these occur rarely and are of little importance, as, for instance, *hollow-stalk*, which has been observed only occasionally. *Bud-scald* was prevalent in the spring of 1919 in some fields which were planted during the extremely hot dry period in the latter part of June. The injury was not noticeable until the plants had been in the field ten days or more. The midribs of the bud-clasping leaflets were the parts most seriously affected, and, as a result of the killing of some of the cells on the underside of the midribs of the leaves which were closed over the bud, these failed to develop naturally, and the normal development of the leaf web and the upper side of the midrib caused the pair of leaves affected to bend sharply downward and grow very irregularly. Never more than one pair of leaves was found affected on any one plant. This injury, while sometimes resembling the type of injury caused by bud-worm, is quite distinct from it. *Sun-scald* of the leaves is, of course, something which cannot as a rule be prevented, and is usually noted on the leaves which have been turned over by the wind, exposing the under side to the hot sun. If water droplets collect on the leaves when in this position, and they are then exposed to the hot sun, there develops on the exposed areas a peculiar type of leaf spot due to burning, the water drops acting as lenses. *Fertilizer-burning* was noted in a few cases, but was usually found only in seed beds which had been treated with a large amount of quick-acting nitrogen to hasten their growth. Elsewhere in this report are noted observations on the overapplication of ground fish to tobacco beds. *Albinism*, a condition in which parts of the leaf are almost pure white while the rest of the leaf is normal green in color, has been noted rarely, and its occurrence is of little import. This condition may arise from a variety of causes, and has even been observed as a result of early frosts, but usually the plants outgrow the trouble and develop green coloring matter in the white areas.

There has been found a root-rot which is more or less similar in its effects to that caused by Thielavia, with the exception that there are no pronounced black lesions on the roots, but a more uniform browning and dirty discoloration, most of the injury being found on the fine, feeding rootlets, and not on the larger ones, as is often the case in a Thielavia infection. A form of Rhizoctonia has been isolated from diseased roots, but as yet it has not been possible to make satisfactory reinoculations with the cultures obtained. It would appear, so far as our observations go, that the fungus may be weakly parasitic in nature. There is a "damping-off" trouble, due to Rhizoctonia, which is found in the seed bed, but in this case infection is usually found near the surface of the ground, and often when such diseased plants are set in the field there results, under favorable conditions, the disease of the stem known as "stem-canker." The root-rot apparently due to Rhizoctonia is usually found in restricted localities

in a field, and as yet is probably not of wide distribution. It remains to be proven whether the fungus is actually actively parasitic, or is capable of attacking only those plants which have become weakened by some other cause. As opportunity offers, work on this disease will be continued.

Root-rots, apparently induced by Fusaria or closely related forms of fungi, are seemingly on the increase, if we may take the isolation of these forms from diseased roots in almost pure culture as an indication of the causal agent. The roots of a large number of plants from patchy fields have been examined in the laboratory in the past two years, and in many cases forms of Fusarium, or closely related forms, have been isolated from the surface of the diseased roots. So far the few experiments in which it was attempted to infect the roots of healthy plants with pure culture material in the laboratory under control conditions have failed. It is a fact, however, that on many of the poorly developed plants in some fields we are consistently finding this fungus. A critical study of the question of Fusaria as the cause of a tobacco root-rot is being made by James Johnson of the Wisconsin station and the United States Department of Agriculture. In the writer's opinion, however, it may prove a difficult matter to establish the parasitism of this fungus, but it is to be hoped that something definite will result in the way of control measures. It should be noted that in fields where we have found the Fusarium associated with a root-rot of tobacco, there is a noticeable lack of infection due to Thielavia, the ordinary root-rot fungus of tobacco. This would indicate that the conditions necessary for the optimum parasitism of Fusarium are distinctly unfavorable to the development of the Thielavia. If this proves true, as these are both soil fungi, the question of control becomes rather perplexing. If it is shown that the Fusarium under certain conditions of soil reaction is actively parasitic, and these conditions are the ones that we have found to be practical for the control of Thielavia root-rot, the question of the finer adjustment of the soil reaction becomes an important factor, and more difficult of successful application.

Canker, noticeable in the field in 1916 as a decay and blackening of the stem at the ground, sometimes extending up the stem for some distance and occasionally girdling it, occurred only in isolated cases, and was of no importance economically. The direct causal organism, or organisms, is not well known, but the primary cause is probably due to a slight attack of damping-off in the seed bed, or even mechanical injury at the soil level, secondary organisms then gaining admission through the weakened tissue. So far the only field found to contain any considerable amount of canker is one to which very large amounts of manure were applied annually, the seed bed also being treated similarly. This excessive amount of organic matter furnishes a very favorable medium for the growth of bacteria and fungi, especially in the seed bed.

The leaf spots observed may be roughly divided into two classes, — those caused by organisms, and those with which no organism is associ-

ated. The second class is by far the more prevalent, and only in rare cases during 1916 were organisms found associated with a leaf spot. The amount of damage caused by leaf spots of this character is apparently slight, judging from the data at hand, but it is possible that more extended examination of fields may show different results.

The leaf spots not due to organisms were rather numerous in 1916, especially those classed as "rusts" by growers. One type of these "rusts" is usually found associated with the mosaic disease, and here the rusted spots which are made up of dead tissue are rather large and often coalescent, so that a comparatively large leaf area may be affected. Another type of "rust," believed by the writer to be associated also with the later stages of mosaic, was observed. In this case the spots were small, more regular in outline, not coalescent, and more thickly distributed over the leaf. There is some question, however, whether this type is always associated with the mosaic disease, as the same condition has been observed occasionally on plants not affected with this disease. In some shade-grown areas another type of spot or "rust" was observed, and it was not associated with mosaic. Here the spots were small, regular in outline, and widely scattered, some of the leaves showing only one or two such spots. It is not certainly known what the cause of this type of spot is, but it resembles a spot found in other tobacco sections where a lack of potash is said to exist. It may be due to other causes, however, and it is useless to even hazard an opinion on the question at this time. The whole matter of leaf spots requires investigation, particularly those spots which are not caused by organisms. It is expected that a study of these troubles will be taken up at a later date.

Mosaic disease was present in 1916 on many fields, but from an estimate of the amount on fifty-one areas it was apparently not present to so large an extent as in some years, approximately less than 3 per cent of the plants having the disease on commercial leaves. No account was taken of plants contracting the disease on the sucker growth appearing after topping, as it is believed that the presence of the disease on such growths does not affect the commercial leaves. The percentage of infection, in general, that season (1916) was below what may be considered the normal infection. (This count, however, included three very badly infected fields where a large percentage of the crop was affected, and this raised the percentage of infection considerably.) The prevalence of mosaic disease seems to be less than it was some years ago, and there has been only relatively small damage from this trouble in the tobacco section, as a whole, in the past two or three years. If more attention is paid to careful handling of plants in removal from the seed bed and during transplanting, the damage resulting from this disease can be reduced to an almost negligible amount. More attention should also be paid to fitting the land and keeping it in the best condition during the transplanting time and until the plant has obtained a good start. There is no question but that proper attention to such details and to the rejection of diseased plants in the seed

bed will go far towards controlling the trouble, but it is improbable, owing to its nature, that it will ever be entirely eradicated. A good indication as to whether an infection is from the seed bed may be obtained by making a note of the time, after planting, of the first appearance of the disease in the field. If the disease is noticed at any time within a period of two weeks after setting, one may be sure that the infection came either from the seed bed or during the transplanting. If it appears after this length of time it is usually the resultant of a field infection. If all the leaves show the trouble it may also be stated that the infection came from the seed bed or from the conditions under which the plants were set. If it appears on some of the upper leaves at a later period the infection occurred in the field, and soil conditions should be looked into. A full discussion of the mosaic disease will be found in Bulletin No. 175 [1] of this station, a copy of which will be mailed on request to the director's office.

Thielavia root-rot, or the ordinary root-rot of tobacco, is probably the most widespread trouble of fungous origin we have in our tobacco fields, and as a primary and secondary cause of many of our "sick" fields it is of great importance.

This disease appeared to be more destructive in 1916 than usual, although the amount could not be compared with that of 1915, as no extended examinations were made during that season. Many fields presenting an unthrifty appearance were studied with the idea of obtaining data as to the presence of root-rot, but in some cases only slight infections were found, the root systems of the plants not being parasitized sufficiently to account, in our opinion, for the general unthrifty appearance of the field. However, some cases were observed where the plants on entire fields were, to a large extent, badly infested with the root-rot fungus, and unquestionably these fields are in need of immediate treatment looking toward the eradication of this trouble. In nearly every case these heavy infections were on fields long used for growing tobacco, and the soil reaction and other factors were rather abnormal. It would appear from the observations made during the season of 1916 that in our fields the causal organism of Thielavia root-rot is widely distributed, but produces noticeable ill effects only when the soil and its environment are unfavorable to the best development of the tobacco plant and favorable to the rapid development of the root-rot fungus.

The control of this disease in the seed bed has already been discussed. There is no question but that it can be completely controlled by thorough sterilization either by steam or formaldehyde. The control of the disease in the field is an entirely different matter, however, and it is practically out of the question to attempt to eradicate it in the field by methods used for its eradication in the seed bed, because of their prohibitive cost. Even if the cost of material were considerably less than it is at present the labor and time factor would render such methods prohibitive. It is believed by some that a method of control by steam or formaldehyde can be devised, and that it will not be impossible of application from the

[1] Chapman, G. H. Mosaic Disease of Tobacco. Mass. Agr. Exp. Sta. Bull. No. 175 (1917)

economic point of view; but so far this has not been done. It may be possible to apply some compound in a dry state to the field, and to do it economically, but any application of a salt in solution would demand so much water to obtain the requisite penetration that it would be out of the question. So far a dry compound possessing the requisite fungicidal action has not been discovered. Certain solutions and salts have been used experimentally, but unfortunately none can be recommended for use on a commercial scale. A brief statement of the results obtained in our experiments with various compounds will be given below. It is believed that control can be better obtained by changing the soil reaction to a more acid condition by means of fertilization and cover-cropping, as has been indicated. The whole question of the prevalence of root-rot and its infection in our fields is closely bound up with the question of soil reaction, and it can hardly be profitably discussed apart from that problem. We have been able, by the use of cover crops and acid fertilizer materials, to "bring back" some heavily infested fields in a remarkably short time, and have no hesitation in recommending the use of a timothy cover crop and the non-application of lime to fields infected with the Thielavia root-rot. Of course there may be danger of getting our soils into a condition too acid for the best growth of tobacco, and judgment should be used in the application of any raw acid materials. The grower should not forget that "while a little may be a good thing, too much may be highly injurious." An increase in the amount of phosphoric acid, applied in the form of acid phosphate, has been found to have a beneficial effect, and apparently does not adversely effect the quality of the tobacco. In our experiments application of both "aged" and "raw" acid phosphate, in amounts of 400 and 600 pounds additional to the acre, has given uniformly good results, particularly on the lighter soils.

Thielavia Root-rot Investigations.

A statement of the results of some of our experiments having to do directly or indirectly with the Thielavia root-rot has been made in connection with other lines of work. Some of the experimental work, while interesting and fundamental from the scientific standpoint, can hardly be made use of at present as a basis for the treatment of infested fields. As a matter of record, however, a brief discussion of experiments is included in this report. The first work undertaken was the attempt to control the disease in the field by the application of chemicals to the soil. The data presented represent the work of two years. The plots were located on fields known to be heavily infested with Thielavia root-rot. The substances used were formaldehyde, copper sulfate, iron sulfate, mercuric chloride, potassium permanganate, sulfuric acid, sulfur, and "By-product A," a commercial preparation. With the exception of the sulfur and "By-product A" the substances were all applied in solution. All plots were in duplicate. The following table will indicate the amounts applied, calculated to an acre basis. A check plot (no treatment) was left between every two plots.

TABLE V. — *Chemicals applied, and Rates of Application.*

	Pounds per Acre.		
Formaldehyde,	4,800	2,400	1,200
Copper sulfate,	400	200	100
Iron sulfate,	1,000	500	50
Mercuric chloride,	100	75	25
Potassium permanganate,	300	100	50
Sulfuric acid,	1,200	600	300
Sulfur,	2,000	1,500	1,000
"By-product A,"	4,000	2,000	1,000

The sulfur and "By-product A" were applied dry and thoroughly mixed with the 3 inches of top soil. The formaldehyde was so diluted that it was applied at the rate of one-half gallon of solution to the square foot of surface. On the first year's plots observations of a miscellaneous character were taken in addition to the root-rot data. The observations relating to growth are noted in the following table. They were made two weeks before harvesting. The growth data are calculated on the basis of the checks equalling 100, the plots being greater or less than this.

TABLE VI. — *Table showing Development of Tobacco in 1917 on Chemically Treated Plots.*

Chemical.	Amount applied (Pounds per Acre).	Color.	Growth (Check = 100; no Treatment).
Formaldehyde,	4,800	Normal,	100
	2,400	Normal,	125
	1,200	Normal,	125
Sufuric acid,	1,200	Normal,	125
	600	Normal,	100
	300	Normal,	100
Sulfur,	2,000	Light,	40
	1,500	Normal,	60
	1,000	Normal,	100
Mercuric chloride,	100	Normal,	45
	80	Very dark,	90
	25	Very dark,	100
Copper sulfate,	400	Normal,	100+
	200	Normal,	110
	100	Normal,	110
Ferrous sulfate,	1,000	Light,	94
	500	Normal,	87
	250	Normal,	100
Potassium permanganate,	300	Normal,	87
	100	Normal,	85
	50	Normal,	85
"By-product A,"	4,000	Normal,	94
	2,000	Normal,	94
	1,000	Normal,	100

It will be noted that the only substances which did not have an inhibiting action on the growth were formaldehyde, sulfuric acid, and copper sulfate. The rest of the chemicals applied did inhibit the growth of the tobacco, at least in the amounts applied.

A careful examination of the root systems of the plants in the different plots was made by Mr. Krout of this department, who was in direct charge of the root-rot work, and he reported as follows: —

Table VII. — *Comparison of Treatment with Thielavia Infection and Root Development.*

Chemical.	Application (Pounds per Acre).	Thielavia Infection (Check Infection=100).	Root Development (Check=100).
Formaldehyde,	4,800 2 400 1,200	0+ 15 15	100 150 125
Sulfuric acid,	1,200 600 300	88 95 88	75 103 125
Sulfur,	2,000 1,500 1,000	80 70 80	38 65 90
Mercuric chloride,	100 80 25	83 83 88	78 88 90
Copper sulfate,	400 200 100	75 85 90	123 108 108
Ferrous sulfate,	1,000 500 250	90 90 100	70 95 115
Potassium permanganate,	300 100 50	90 60 95	100 100 100
"By-product A,"	4,000 2,000 1,000	100 88 90	93 105 95

From the above it may be seen that the only substance used which checked the development of the root-rot, or controlled it to any great extent, was the formaldehyde. The root growth also was apparently stimulated by the lower concentrations. Sulfur, mercuric chloride, and ferrous sulfate, while reducing the root-rot to some extent, had an injurious effect on root development. The copper sulfate and sulfuric acid reduced the amount of root-rot infection somewhat, and did not apparently, except in the case of the greatest strength of sulfuric acid, reduce the root development to any extent.

These experiments were continued in the following year with comparable results. It would seem that none of the substances used, with the exception of formaldehyde, were sufficiently beneficial in their action to warrant

further experimental work at this time. The cost of this material and the labor involved, together with the large amount of water which is necessary, render it inadvisable to recommend this treatment on large areas. Small areas in a field might be so treated.

The sulfuric acid treatment did not give the results anticipated, but possibly a variation in amount applied might give more beneficial results. In this case, however, we should have to take into consideration the possible residual effect of the SO_4 radical (sulfate). Further data on this point will be available later. It would seem that, in view of the fact that Thielavia is so susceptible to acids, this might be a method of at least partial control.

The benefits to be derived from increasing the organic matter and general condition of the soil, in relation to the Thielavia root-rot, have already been briefly discussed, and further mention of them will be omitted.

Much laboratory work is in progress with the Thielavia fungus to determine the specific action of the different acids and bases on the growth and development of the fungus in culture, as well as to determine the limits between which the fungus is actively parasitic. The results, however, will not be discussed in this report, as additional work is necessary on this phase of the problem.

Fertilizer Experiments in Progress.

Beginning in 1917 there were established three experimental field plots on different soil types in the tobacco section. The yields on these fields were very low, so low on one of them that the crop had not been harvested. On one of the fields there was abundant evidence of a very serious Thielavia root-rot infection; on the other two, however, although the root-rot was present it did not appear to be of primary importance.

The experiments were designed to be general in character, and dealt with three principal questions, namely: (1) Are our soils in need of organic matter, and if so what is the response of the crop to the direct addition of the same in the form of peat, or in the form of stable manure? (2) Are our soils lacking in potash, owing to the inability of the growers to procure the usual amounts of the same since 1914, and if there is a lack how is it evidenced? (3) What benefits, if any, are to be derived from the addition of increased amounts of phosphoric acid in the form of acid phosphate to the normal fertilization? This question was suggested by the fact that very good results have been obtained in many cases by rotating tobacco and onions, and the latter crop is usually treated with a fertilizer containing a large amount of acid phosphate.

The results of 1919 are not at present ready for publication, but some rather definite results were obtained in 1917 and 1918. These will be briefly discussed here. The details of the experiments will not be taken up in this report, as the work is of sufficient volume to require a separate report, which is to be issued as soon as possible after the 1919 crop has

been gone over and the results tabulated. Two of the plots were Havana and the third Cuban shade-grown. There has been a general similarity shown by the results on all of the plots.

In addition to the special treatments indicated below, it should be remembered that all the plots received an application of a 5–4–5 mixture, equivalent to an application of 3,000 pounds of commercial mixed goods of the same analysis per acre, except, of course, the no-potash plots. These received no potash in any form, except such as was in the manure or the cottonseed.

There was a marked increase in yield both in 1917 and 1918 on the plots which had received an application of organic matter in the form of peat at the rate of 2 tons to the acre (on a 12 per cent moisture basis), and also a slightly heavier yield with better quality on the manure plots than on the peat, the manure being applied at the rate of 10 tons to the acre. There was a still more marked increase in yield on the plots which had received organic matter, either as peat or manure, and acid phosphate at the rate of 300 to 600 pounds per acre. Where acid phosphate alone was used in conjunction with the regular fertilization without the addition of organic matter in some form the results even on the same plot were sometimes rather conflicting. It can only be stated that no uniformity of results was obtained. In some cases a marked benefit was noted as a result of the treatment; in others, on the same field, the results were apparently negative.

With respect to the lack of potash it was noticeable that there was no lack of this material indicated on any of the plots in 1917 and 1918. No differences were observed, so far as this material was concerned, between the plots which received applications of 350 pounds of high-grade sulfate of potash and those which received none at all. It should be stated, however, that the experimental plots were all located on land which had in the years prior to 1914 received liberal applications of potash, and it is quite probable that the supply of available potash in the soil was in no case exhausted. During the growing season of 1919 there were indications that on one of the fields there might be developing a lack of potash. The symptoms were not characteristic enough to warrant a positive statement on this point.

There is no evidence that our soils in general are suffering from a lack of potash, although a few local areas where this was the case have been brought to our attention during the past year. These cases were all on light soils and on soils which had not in the past received any heavy applications of potash in the fertilizer used. It would appear that new soils which have been used for a comparatively short period only before the shortage of potash are more liable to be suffering from a lack of potash than are some of the old fields which have for years received a very liberal application of this material. On these fields it is probable that there is an accumulation of potash in the soil sufficient to have carried the crop over the period of the shortage.

Organic matter, of course, can be economically applied to the soil in the form of a cover crop, as has already been mentioned, or as manure. This latter method is the more costly if all manure has to be bought, but some manure should be applied from time to time to get the best development of tobacco, apparently, although it is true that many growers are at present using commercial fertilizers and cover crops alone with good success.

The increased growth on acid phosphate in conjunction with applications of organic matter is conspicuous and rather difficult of explanation, aside from the points brought out in the discussion of the question of soil reaction. The tobacco plant uses very little of the available phosphoric acid of the soil, and certainly for direct fertilization effect, or as a food material, the plant needs only a small amount of the phosphoric acid available. It might be well to caution against the use of very large amounts of acid phosphate on our heavier soils year after year, as there is a tendency for this material to darken the leaf, and also, on account of the sulfate or sulfuric acid contained in it, to injure the burn. In our experiments, however, this has not occurred as yet.

Miscellaneous Observations.

Other Root-rots.

While making an examination of the roots of plants from a field which had presented an unthrifty appearance all season (1916), but on which very little root-rot (Thielavia) could be found, it was observed that certain of the plants showed a peculiar discoloration of the root stock just below the surface of the ground. The only organism isolated was a species of Actinomyces, which was characterized by Dr. P. J. Anderson of this department as differing, apparently, from the ordinary forms found in our soils. No connection has been established as yet between the presence of this fungus in soils and its relation to the tobacco plant. No infection experiments have been made, but a study of this organism, if found again, is projected. Forms of Fusarium were also isolated from this and other material, but their rôle is problematic.

"Mammoth" Types of Cuban and Connecticut Havana Tobacco.

From time to time there have appeared in the fields of Connecticut so-called "mammoth" plants of Cuban and Connecticut Havana tobacco. Beinhart and Hayes first experimented with the mammoth Cuban type found in Connecticut on the plantation of the Windsor Tobacco Corporation by its manager, Mr. J. B. Stewart, from whom the type takes its name, "Stewart Cuban." This mammoth type was first grown commercially in 1914, and was found to cure in a very satisfactory manner.

At present the Stewart Cuban, or a very similar mutant, is being grown not only in Connecticut, but in Massachusetts as well to a limited extent.

It apparently is also satisfactory to the trade, which is essentially the final test of all tobacco.

In 1912 and subsequently, mammoth mutants have been quite frequently found in fields of Connecticut Havana. In 1916 our attention was called to two plants in a field in Sunderland by Mr. Frank Hubbard. These plants were darker green in color and had a larger leaf than did the average plant, and showed no indication of budding when the plants in the rest of the field were ready for topping. The number of leaves per plant was also greater, and they were set much closer together on the stalk. These two plants were removed to the greenhouse early in September and allowed to mature. It was not until mid-April of the following spring that the plants blossomed, and seed could not be obtained until May.

Before transplanting to the greenhouse there were primed from these two plants thirty-eight and forty-six leaves, respectively. It was reported that these leaves cured satisfactorily. At the time of blossoming there had been produced on the main stalk of each plant one hundred and thirty and one hundred and ten leaves of sufficient size to be called marketable.

In 1918 some few hundred plants were set in two fields, one in Southwick, on the farm of Mr. C. H. Granger, and one in Sunderland, on the land of Mr. Frank Hubbard.

The comments of the growers are as follows: Mr. Granger said, "I primed forty to fifty leaves from a plant, but they never cured right, and about the only recommendation I can give this tobacco is a fine-shaped leaf and increased weight. I topped some of it but got no better results."

Mr. Hubbard reported that he was much pleased with the type and habit of growth, but that as the plants were not set on what he would consider prime tobacco land he would prefer to try it again. Some of the tobacco he had bulk-sweated, and it came through rather better than was expected. The leaf had a good body, vein, etc., but contained little or no light wrapper, consisting principally of medium and dark wrapper and binder. The taste and burn were fairly satisfactory. The yield, in comparison with the ordinary type of Havana, was approximately doubled.

Further work with this type of tobacco, looking toward improvement of quality by varying the fertilization and also a method for maturing seed earlier, is in progress. It is believed that this mammoth type of Connecticut Havana may possess commercial possibilities.

High-pressure versus Low-pressure Seed Bed Sterilization.

It has been universally recommended that in sterilizing the seed beds with steam, as high a steam pressure as possible be maintained at the boiler, usually from 75 to 125 pounds, and that the steam be allowed to act under the pan for from twenty to thirty minutes in order to insure thorough sterilization.

Low-pressure outfits developing around 20 pounds pressure have been

used, and in many instances with entirely negative results so far as killing disease-producing organisms was concerned.

It has been stated by some growers that they were absolutely sterilizing their beds with low-pressure steam in the same time as with the high-pressure outfits. There is no question but that certain types of soils will permit the use of low-pressure, providing the soil is in exactly the right mechanical condition and has a minimum water content. This has been done experimentally and practically on light porous soils, but unless the grower is assured by thermometer readings, or the complete cooking of potatoes at the desired depth, that the soil is sterile, it is apt to be a costly and futile undertaking.

It is much safer to use high-pressure outfits, particularly when the work is done by outside parties. In any event, the grower should assure himself that he is sterilizing the soil and not merely killing a few weed seeds. For general application the high-pressure method should be used; the low-pressure method will sterilize, but economically it has only a very limited range of application on certain soils. Usually there is too much guesswork in sterilization.

Vitality of Tobacco Seed.

It has been generally believed that the seed of tobacco retains its vitality for a number of years, even up to twenty. This may be true in exceptional cases in which the seed has been preserved under ideal conditions, but usually after the tenth year the vitality of our seed is so much reduced as to render it unfit for use, even when preserved under the best conditions.

A grower, however, often wishes to use a particular lot of seed a number of years, and it is of interest to know approximately, at least, what the germination of seed of the different varieties is at different ages. The maintenance of vitality, of course, depends to a great extent on the conditions under which the seed is kept, and this factor should be taken into consideration in drawing conclusions as to the germinability of the seed. In the following table are given some of the results obtained with seed of different ages kept under excellent conditions in a cool, dry place, either in muslin bags or wide-mouthed glass containers plugged with cotton: —

TABLE VIII. — *The Vitality of Tobacco Seed of Three Varieties preserved properly for Various Lengths of Time.*

Variety.	Age of Seed (Years).	Test No.	Per Cent of Germination at Two-day Intervals. 2	4	6	8	10	12	Average.
Broadleaf,	10	1 1*a*	0 0	0 0	0 0	0 0	16 12	45 55	50
	9	2 2*a*	0 0	0 0	0 0	12 0	21 16	67 65	66
	5	3 3*a*	0 0	0 0	58 62	89 92	95 96	95 96	95.5
	2	4 4*a*	0 0	0 0	60 54	85 80	88 91	90 93	91.5
Havana,	37	5 5*a*	0 0	0 0	0 0	0 0	0 0	0 0	0
	25	6 6*a*	0 0	0 0	0 0	0 0	0 0	0 0	0
	9	7 7*a*	0 0	0 0	0 0	0 0	0 0	2 1	1.5
	6	8 8*a*	0 0	0 0	61 58	68 68	– –	– –	68
	4	9 9*a*	0 0	– –	– –	95 92	– –	96 95	95.5
	2	10 10*a*	0 0	0 0	– –	– –	98 100	98 100	99
Cuban,	6	11 11*a*	0 0	0 0	8 18	22 35	41 41	54 45	49.5
	4	12 12*a*	0 0	0 0	23 31	74 66	88 84	– –	82
	2	13 13*a*	0 0	0 0	27 28	86 90	91 95	– –	93

Considerable variation will be noted in the above table, and perhaps a larger series would have changed the results somewhat, but it was impossible to find seed saved under these conditions. The results at least serve as an indicator of the probable vitality of these varieties. The Broadleaf variety apparently retains its vitality longer than either the Havana or Cuban.

A few samples from tin cans and corked bottles were germinated at the same time with the following results: —

Five-year-old Broadleaf germinated only 31 per cent.
Three-year-old Broadleaf germinated only 72 per cent.
Two-year-old Havana germinated only 87 per cent.

Seed should be thoroughly dry when placed in containers, and some means of ventilation, or better, aëration, should be provided; otherwise the accumulation of moisture in the containers will be very conducive to

mold growth. Seed preserved in cloth bags in a cool, dry place will retain its vitality longer, and give higher percentage of germination, than seed stored in air-tight containers.

Top-dressing Tobacco Seed Beds with Dry Ground Fish.

It is the custom of many growers to top-dress the tobacco seed beds occasionally with some quick nitrogen fertilizer, such as ammonium sulfate, nitrate of soda, commercial "starter," or fish. The danger of using an excess of the three former is pretty well recognized by the growers, but in the use of dry ground fish not so much attention has been paid to the amount used, as it has been claimed that it is impossible to apply an excess of this material.

This view is erroneous, as at least three cases have been noted where an excess has been applied, the "burning" of the plants taking place four to six days after application. In all cases the plants were thoroughly sprayed and the fish well washed off the leaves. Experimentally, the same applications proved injurious in all three cases. The mechanical condition of the fish seems to play a very important part in the injury, as in all three cases the fish was very finely ground, and in all probability the nitrogen was more quickly available than with other coarser or less nitrogenous fish.

No set rule as to the amount to be applied can be given, but as much discretion should be used with fish as with the ammonium sulfate or sodium nitrate, as the loss of the beds from top-dressing is a very serious matter.

As a matter of fact, beds properly fertilized should not need any application of nitrogen except, perhaps, after they have been pulled over several times. While a large, apparently vigorous growth is obtained when the bed is repeatedly top-dressed with nitrogenous fertilizers, the plants are apt to be tender and succulent, and will not stand transplanting so well.

Summary.

1. *The yield of tobacco in Massachusetts has not been gradually decreasing during the past ten years. Since 1914 the yield has been low, but this is due to adverse climatic conditions primarily.*

2. *In general, rainfall is the major limiting factor of growth (and this necessarily includes soil moisture along with it), together with temperature.*

3. *Excessive seasonal rainfall is invariably followed by a reduction in yield, independent of temperature.*

4. *Subnormal rainfall, when accompanied by temperatures excessively above normal, reduces the yield.*

5. *Subnormal rainfall, when accompanied by subnormal temperatures, does not apparently reduce the yield to any extent unless the rainfall is very much below normal.*

6. *There are, undoubtedly, in many localities specific problems to be worked on, such as the effects of improper fertilization, methods of culture, and control*

of disease-producing organisms; but these are "specific" and not "general" troubles as yet.

7. *The tobacco soils of Massachusetts fall into three groups, as regards acidity or "lime requirement." Soils with a "lime requirement" up to 3,000 pounds CaO per acre are not producing good crops, as a rule, and are comparatively free from root-rots. Those with a "lime requirement" of from 3,000 to 8,000 pounds CaO per acre are in good tobacco condition; but in this group pathogenic fungi are abundant in the soil, and the plants, during certain seasons, are very liable to suffer from root-rots caused by some of these fungi. Soils with a "lime requirement" of 8,000 pounds CaO up are usually comparatively free from such fungi, and even in unfavorable seasons little disease is found, but the tobacco is perhaps of slightly inferior quality.*

8. *Most of the tobacco soils in Massachusetts are deficient in humus or organic matter.*

9. *To supply this lack of organic matter cover crops, preferably timothy, should be planted and plowed under.*

10. *No satisfactory field soil treatment for the Thielavia root-rot has been worked out.*

11. *Many of the so-called "sick" soils are responding favorably to additional applications of organic matter and phosphoric acid in the form of acid phosphate. Care should be exercised in the application of these materials to guard against excess.*

12. *Our fields, generally, are not yet suffering from a lack of potash, as determined by plant growth and development.*

BULLETIN No. 196.

DEPARTMENT OF AGRICULTURE.

METHODS OF APPLYING MANURE.

BY WM. P. BROOKS.

Introduction.

The question as to the best system of handling and applying manures is one which has always excited a great deal of interest, and is of very special importance at this time. The reasons which have given the question exceptional importance in recent years are several. Among the more prominent are these: —

1. The increasing insistence, on the part of those using the product of our dairy stock, not only that manure shall not be stored, as was formerly the custom, in a cellar beneath the stable, but that it shall be promptly taken away from the vicinity of the stable.

2. The increasing cost of the labor of taking manure from the stable to the fields where it is to be used.

There are, of course, great possibilities of variation in methods adopted, but one of the most prominent in the minds of those making use of manure has been the question as to whether, when removed from stable or other place where it has accumulated, it is advisable to spread it at once upon the land, irrespective of the season of the year when it must be so removed, or whether provision should be made to store it in some manner and hold it until it can be incorporated with the soil. This has always been a question upon which there has been a great difference of opinion, both plans having earnest advocates, especially the plan of spreading manure as fast as it must be moved, on account of reduced cost of labor connected with its application under that system, and reduction of the pressure of farm work in the spring. The experiment described in the following pages was planned with a view to throwing light upon this question.

The experiment began in 1900. The land available for use in the experiment lay on a moderate slope from the east toward the west, which was fairly uniform, though not quite ideal in respect to uniformity, and which lay at an angle with horizontal of about 4½ degrees. The location

is near the foot of the west side of a drumlin of moderate elevation. According to a soil survey made by the United States Department of Agriculture the soil is of that type for which the name Holyoke Stony Loam was suggested. It is a type of soil which with minor variations is very common throughout Massachusetts, and is known in the ordinary language of the farm as a moderately strong gravelly loam, with good capacity for retaining and conducting moisture, and somewhat affected, more or less unevenly as is pointed out in another connection, by seepage water which tends toward the surface from the higher portions of the drumlin as it finds its way downwards.

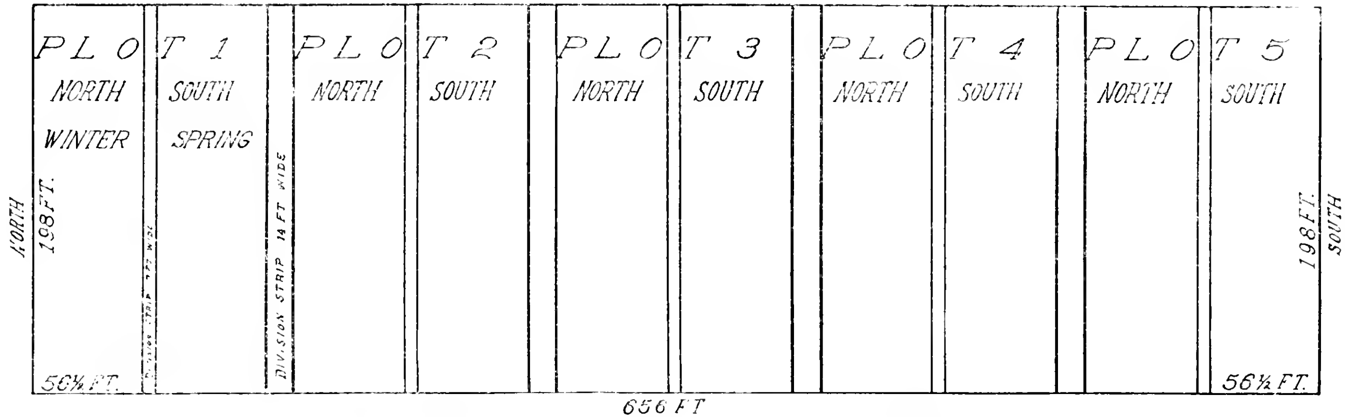
The land referred to had been used in an orchard experiment designed to test the relative results of different systems of manuring continuously followed from the year previous to the setting of the nursery stock. The kinds of fruit which had been used in the orchard experiment were peaches and pears. The land used was divided into five equal plots, each of which was uniformly manured annually from 1889 (the year previous to the setting of the trees) until 1897, both inclusive. As already indicated, the trees were set in 1890. The land proved unsuited to the peach and pear, a number of the trees died quite early in the experiment, and, since the number lost in different plots differed widely, it was decided to be inexpedient to continue the experiment with these kinds of fruit. Both manure and fertilizers used while the land was in fruit were applied broadcast in the early spring.

Plan of the Experiment.

The statements concerning the history of the area used in the experiment to be described have made it apparent that we had available five plots lying side by side upon a fairly even slope which had been respectively subjected to a widely varying fertilizer treatment. It is at once apparent that results on these plots could not be compared one with the other in such a way as to throw any light upon the question of the relative effects of different methods of applying manure. Accordingly each of the original orchard plots was divided in the middle by a line running directly up and down the slope. The different original plots were separated by unmanured or fertilized strips of land 14 feet wide, while the two halves of each of the original plots as laid out for the experiment under discussion were separated by a strip 7 feet in width. For purposes of record it was decided to retain the original orchard plot numbers, and to make the application of manure to the north half of each plot in winter, that to the south half in spring. The system followed to insure as closely as possible absolute equality in amount and kind of manure applied to north and south plots was as follows: —

All the manure used on plots 1 to 4, both north and south halves, was the product of the experiment station herd of milch cows. These cows were liberally bedded with baled planer shavings. The floor upon which the cows were kept was watertight, and the manure was removed at

PLAN OF PLOTS. MANURING EXPERIMENT.



FERTILIZER TREATMENT, 1889–97.

Plot 1, manure, 10 tons per acre.
Plot 2, wood ashes, 1 ton per acre.
Plot 3, nothing.
Plot 4, ground bone, 600 pounds per acre; muriate of potash, 200 pounds per acre.
Plot 5, ground bone, 600 pounds per acre; low-grade sulfate of potash, 400 pounds per acre.

MANURING EXPERIMENT, 1900–19.

Manure applied annually, 1900–11 (with the exception of 1907), at the rate of 10 tons per acre.
North half, winter application.
South half, spring application.
Plots 1 to 4, cow manure; plot 5, horse manure.
Plot 1, early winter; plot 4, late winter.
No manure applied since 1911.

least twice daily to concrete pits, watertight and roofed. There were two pits. Manure was allowed to accumulate in the pits until the amount was sufficient to supply the needed quantity for an entire plot. The manure was then conveyed to the field, being weighed load by load as it was moved. (In referring to the different plots, the north half will be designated as "N," and the south half as "S." The arrangement and previous history will be understood by reference to the plan, page 41.)

The first load of manure was spread on plot N; the second load taken out was dumped into the foundation of a heap to be built out of the manure which was to be spread in the spring (this being located on some part of plot S, differing from year to year). Alternating loads were taken, respectively, to N and S, and either spread on N or added to the heap on S. The total weight when removed from the pits to the field as described was the same for both N and S. The annual application was at the rate of 20 tons per acre.[1] In building the heap on S, it was the practice to drive over what had previously been dumped as long as possible; and when all the manure had been taken out, the heap was squared up and was usually about 4 or 5 feet in height, with sides nearly perpendicular. In other words, the manure was so piled as to expose it as little as possible to danger of loss through washing and leaching. As has been indicated, care was taken in successive years to place the heap of manure on the different plots S on different parts of the plot, in order to equalize as far as possible any effect due to leaching of material directly from the heap into the soil beneath and in its immediate vicinity. Manure held in heaps from the time it was hauled out until spring was in all cases allowed to stand in the heap, when a hoed crop was to follow, until the soil could be worked. It was then spread on the plot on which the heap stood as evenly as possible, and then the entire area, including that to which manure had been applied during the winter, was disked, thus at once mixing the newly spread manure with the soil. When the land was in grass the time of handling the manure from the heap was practically the same as when the land was to be put into a hoed crop, and after spreading the manure from the heap upon the mowing it was the usual practice to go over the entire area, winter as well as spring applications, with a brush, for the purpose of fining and promoting a more even distribution of the manure. The manure held in heaps on all plots was almost invariably all spread in each year on the same day, or, if conditions rendered this impossible, the work once begun was completed at the earliest possible moment.

When the land was to be put into a hoed crop the following year, it was either sown to a cover crop of rye the previous fall or plowed late in the fall across the slope of the field. No attempt was made to vary the date of application according to variations in the field conditions as regards covering with ice or snow or freedom therefrom, and any one

[1] A cord of undecomposed, well-saved cow manure from animals moderately bedded with planer shavings weighs about 3 tons.

familiar with the New England climate will understand that there was very wide variation in conditions at the time of application. Plots N and S on plot 1 were the first plots supplied with manure except in 1911, when the order was reversed. With the exception of the year just named, plots 2, 3 and 4 were supplied in the order named. The application to plot 4 was therefore, with one exception, either very late in the winter or in the early spring.

TABLE I. — *Variations in Date of Application of Manure and of Spreading from Heaps.*

Plot.	North Half.		South Half.			
	Spread.		Piled.		Spread.	
	Earliest.	Latest.	Earliest.	Latest.	Earliest.	Latest.
1,	Nov. 19	Mar. 13	Nov. 19	Mar. 13	Apr. 4	May 23
2,	Nov. 24	Feb. 26	Nov. 24	Feb. 26	Apr. 4	May 23
3,	Dec. 16	Mar. 31	Dec. 16	Mar. 31	Apr. 4	May 23
4,	Dec. 16	Mar. 28	Dec. 16	Mar. 28	Apr. 20	May 23
5,	Dec. 9	Mar. 8	Dec. 9	Mar. 8	Apr. 4	May 25

The manure applied to plot 5 was of different character. It was obtained from a local livery stable, and was horse manure usually comparatively fresh and containing a moderate amount of straw which had been used for litter. In supplying manure to N and S of plot 5, the plan described in outline for the other plots was followed; that is, alternate loads respectively spread on N and added to a heap on S, the total to N and S being the same for each.

In 1906 the whole field received an application of hydrated lime at the rate of 1 ton per acre. This was applied on the rough furrow and was worked in by the use of the disk harrow.

The experimental system of manuring described was continued annually from 1900 to 1911, both inclusive, with the exception of one year, 1907, when no manure was applied to any plot, and with a few minor variations which seem unimportant in their relation to the results obtained. In preparation for the experiment, the yield of all plots in the field under precisely similar manurial treatment for all was determined in 1899. In this year manure from the station herd of dairy cows was applied by means of the manure spreader driven transversely across all the plots in moderate and in precisely equal amounts to each, as nearly as careful regulation of the machine permitted. The field was planted with corn. There was considerable difference in the total yield of dry matter obtained on N and on S of plot 3, which reference to the plan (page 41) shows was the plot which during the continuance of the orchard experi-

ment had been neither manured nor fertilized. These yields are shown in Table II, as also are the yields of dry matter in 1899 on all the other plots.

TABLE II. — *Dry Matter per Plot after Uniform Manuring in 1899. Ensilage Corn (Pounds per Plot).*

PLOT.	North Half.	South Half.
1,	1,559	1,660
2,	1,758	1,696
3,	756	1,271
4,	1,659	1,551
5,	1,616	1,703

It will be noted that there is but little variation in yield between N and S on the other different original plots, the extreme range being from 1,550 to 1,750 pounds. The results obtained, therefore, indicate that the conditions for the comparison of the two systems of applying manure were fairly satisfactory.

I would, however, call attention to the fact that probably more important than variations in fertility dependent upon differences in plant-food content were differences in moisture conditions on the different plots. The slope used in the experiment lay upon the west side of a drumlin, a geological formation extremely common and highly important in the agriculture of Massachusetts. As is likely to be the case with slopes on drumlins there is a tendency for seepage water, which sinks into the soil farther up on the slope or on the summit, to work outward toward the surface on the lower parts of the slope. During some years and with some crops this movement of soil water exerted comparatively little effect on the crop, but there can be no doubt that in seasons of comparatively heavy rainfall during the period of most active growth, especially of crops such as corn and soy beans which require high soil temperature for best results, it was sufficient on some of the plots to keep the soil cooler and wetter than is desirable for the best yields.

RELATIVE EFFECTS OF THE TWO SYSTEMS OF MANURING ON CROP YIELDS.

Table III shows the crops grown in successive years during the period of the experiment under consideration, and for each year indicates in how many of the five different comparisons either N or S, or one of them alone, gave the larger yields. Attention is called to the fact that the period during which manure was applied annually in accordance with the two plans under comparison was twelve years, and that there were five comparisons each year, or 60 in all.

TABLE III. — *Manuring Experiment, General Character of Results.*

Year.	Crop.	North Half ahead.	South Half ahead.
1900, ...	Corn (grain), ...	1	4
1901, ...	Millet, ...	–	5
1902, ...	Corn (ensilage), ...	2	3
1903, ...	Soy beans, beans, ...	3	2
1904, ...	Corn and soy beans (ensilage), .	3	2
1905, ...	Corn (grain), ...	–	5
1906, ...	Corn (grain), ...	1	4
1907, ...	Mixed grass and clover, . .	2	3
1908, ...	Mixed grass and clover, . .	–	5
1909, ...	Mixed grass and clover, . .	3	2
1910, ...	Mixed grass and clover, . .	–	5
1911, ...	Mixed grass and clover, . .	4	1
	Totals, ...	19	41

Examination of this table shows that, as might be expected by any one familiar with the variations in our climate, results were not consistently favorable throughout the entire period, either to one or the other season of application; but the general average result was most favorable to winter application in 19 out of 60 comparisons, or practically 1 in 3.

The following points appear to be worthy of especial mention. In 1903, the crop being soy beans, the general average based upon results upon all the plots showed that plots N were ahead both in yields of beans and straw. In 1904, the crop being corn and soy beans which were ensiled, the crops were about equal. When the crop was mixed grass and clover the general average was favorable to the North half three years out of five, or in three-fifths of the trials. On the other hand, when corn for ripened grain was the crop, the South half was invariably ahead on the general average.

The general results, therefore, it may be said, appear to indicate that the common practice of top-dressing mowings with manure during the late fall or winter rather than in the spring is wise. If, however, we study Table IV, which shows the percentage results, it will be noticed that the average superiority of the North half is due to the fact that the first, or hay, crop is usually the better under that plan; the rowen crop, on the other hand, is usually better when the manure is spread in the spring, and the degree of superiority as indicated by the higher percentage shown in Table IV for the rowen crop under spring application is usually very high.

TABLE IV. — *Manuring Experiment, Percentage Results.*

Year.	Crop.		Percentage for South Half (North Half = 100 Per Cent).				
			Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 5.
1900	Corn,	Grain,	95.3	108.6	124.7	111.1	132.6
		Stover,	113.2	105.2	125.5	108.9	111.4
1901	Millet,		118.2	131.3	177.0	145.7	148.7
1902	Corn (ensilage),		103.9	97.3	150.0	91.6	108.6
1903	Soy beans,	Beans,	106.9	95.3	95.9	82.5	106.7
		Straw,	118.7	103.7	90.8	81.4	101.4
1904	Corn and soy beans,		92.2	107.4	130.1	92.9	97.2
1905	Corn,	Grain,	102.1	123.6	123.1	119.5	106.4
		Stover,	107.0	108.6	113.3	111.6	105.1
1906	Corn,	Grain,	105.9	122.9	108.4	93.2	102.2
		Stover,	105.9	114.0	107.9	99.1	100.2
1907[1]	Mixed grass and clover,	Hay,	100.3	98.7	107.0	92.9	95.2
		Rowen,	111.1	90.0	87.3	105.6	174.2
		Total,	101.6	97.3	103.5	94.5	101.6
1908	Mixed grass and clover,	Hay,	111.1	116.0	118.8	113.0	93.2
		Rowen,	113.1	115.7	111.8	86.7	143.8
		Total,	111.5	115.9	117.8	108.7	100.7
1909	Mixed grass and clover,	Hay,	81.4	99.4	105.6	86.1	92.0
		Rowen,	244.9	57.5	143.0	123.6	255.7
		Total,	85.7	95.1	107.3	88.7	102.1
1910	Mixed grass and clover,	Hay,	109.7	109.2	98.6	104.4	95.8
		Rowen,	188.9	90.6	131.6	141.0	168.1
		Total,	115.9	106.5	102.0	107.4	102.6
1911	Mixed grass and clover,	Hay,	107.6	101.2	91.6	96.3	104.2
		Rowen,	68.9	45.9	87.4	100.0	94.2
		Total,	100.0	94.1	94.2	96.4	101.5

[1] No manure was applied to either N or S on any of the plots in 1907, the reason being that the growth and general condition of the several plots which had been seeded in the corn in 1906 indicated a high degree of probability that should manure be applied the crop would lodge to a very serious extent. That the decision was wise was indicated by the results, for the crop even without top-dressing lodged considerably. The rate of yield on all plots was considerably in excess of 3 tons per acre for the first crop, and about one-half ton for the second crop on winter application, and considerably in excess of one-half ton where the manure in previous years had been applied in the spring.

Table V shows the rainfall in inches in each of the months of what may be called the growing season, together with the total for the several years. A study of the figures for the several months in the different years and the totals for these years has not sufficed to indicate any well-defined relation between rainfall and the relative standing of N and S. This, perhaps, is not surprising, because conditions affecting the amount of evaporation or loss of moisture from the land surface vary very widely in different years, especially important in this connection being the amount of sunshine, the mean temperature and the direction and amount of wind movement. The fact is we do not know them with sufficient accuracy to determine whether variations in local climate were sufficient to account for the differing results in the different years during which the experiment continued or to enable us to judge how important these climatic variations may have been.

TABLE V. — *Rainfall in Inches.*

YEAR.	April.	May.	June.	July.	August.	September.	Total for Year.
1899,	1.79	1.28	4 13	4 89	2 00	7.90	41.49
1900,	1.85	3 78	3 65	4 67	4.11	3 67	51 67
1901,	5.95	6 91	.87	3.86	6.14	4 17	49.72
1902,	3 31	2 32	4 54	4.66	4.65	5.83	46.99
1903,	2 30	.48	7 79	4 64	4 92	1 66	45 45
1904,	5 73	4 55	5 35	2.62	4.09	5.45	45 30
1905,	2 56	1 28	2 86	2.63	6.47	6.26	38.80
1906,	3 25	4 95	2.82	3 45	6.42	2.59	45 45
1907,	1.98	4 02	2.36	3 87	1.44	8.74	42.27
1908,	1.97	4 35	.76	3 28	4.27	1.73	39.68
1909,	5 53	3.35	2.24	2.24	3 79	4 99	39.12
1910,	3.07	2.67	2.65	1.90	4.03	2.86	36.11
1911,	1.87	1.37	2.02	4.21	5.92	3 41	44 21
1912,	3.92	4 34	.77	2.61	3.22	2.52	38 56
1913,	3 30	4.94	.90	1.59	2.26	2.56	39.50
1914,	6.59	3 56	2 32	3.53	5.11	.52	41.83
1915,	3 99	1.20	3.00	9.13	8.28	1.37	51.58
1916,	3.69	3 21	5.34	6.85	2.49	5.08	45.61
1917,	1.83	4 13	5.27	3 36	7.06	2.42	43.56
1918,	2.78	2.47	4.01	1.84	2.22	7.00	37.47
1919,	2 37	6.20	1.09	4.17	4.81	4 25	41.42

TABLE VI. — *Average Yields.*

Crop.	Average for Five Plots. North Half.	Average for Five Plots. South Half.	Per Cent for South Half (North Half = 100 Per Cent).
Millet (1 year),	3,847 pounds	5,414 pounds	140.7
Corn, ensilage (1 year),	15,890 pounds	16,914 pounds	106.4
Soy beans (1 year), Beans,	15.07 bushels	14.61 bushels	96.9
Soy beans (1 year), Straw,	1,212 pounds	1,193 pounds	98.4
Corn and soy beans (1 year),	22,034 pounds	21,907 pounds	99.4
Corn (3 years), Grain,	37.14 bushels	41.13 bushels	110.7
Corn (3 years), Stover,	4,452 pounds	4,844 pounds	108.8
Mixed grass and clover (5 years),	7,101 pounds	7,250 pounds	102.1
Total weight of crops removed, average of five plots.	100,517 pounds	105,694 pounds	105.2

Table VII indicates the number of times out of the twelve (the total number of years during the period when manure was generally applied annually) in which the yield on N was superior to that on S.

TABLE VII. — *General Results.*

Plot.	North Half ahead —
1,	4 years out of 12
2,	5 years out of 12
3,	2 years out of 12
4,	7 years out of 12
5,	1 year out of 12

Examination of this table shows that on plot 3, S almost invariably gave the larger yield, N being superior to it only two years out of twelve. This may be explained by the greater fertility or better physical condition of S on plot 3, as shown by the yields given in Table II. On plot 5 the general superiority of S was still more marked, N giving the larger yield only one year out of twelve. It will be remembered that the manure applied to plot 5 was from horses, whereas that applied to all the other plots was from a herd of well-fed dairy cows. As has been pointed out, this stable manure was usually comparatively fresh, yet it had without doubt undergone more fermentation previous to being taken to the field than had the cow manure applied to the other plots. The effect of this greater progress toward complete disintegration at the time of spreading must have been to increase the proportion of soluble matter in the manure,

especially the proportion of soluble ammonia and nitrates. It is a conclusion which these facts render extremely probable that the winter-spread manure on plot 5 suffered greater loss than that from cows spread on the other plots.

Further, it will be remembered that the length of time during which manure on plot 1 N was exposed was greater than on plots 2 and 4, and it is probably significant that S gave yields superior to N on plots 2 and 4 more frequently than on 1, a fact which this table brings out clearly.

Varying Effect of the Systems of Manuring on the Cover Crop of Rye.

No effort was made to determine the amount of green rye turned under on the different plots, but careful observations were made on the relative condition on N and S of the several plots. Our records of such observations show that, as would naturally be expected, the growth of the cover crop of rye during the early spring on plots N was superior to that on S. As is well understood, rye grows at an extremely low temperature, and wherever the manure had been spread during the winter the cover crop of rye derived considerable advantage from it. The dates of turning the cover crop under varied quite widely in successive years, being determined in part by peculiarities of season and in part by the crop which was to follow, but the plan adopted did not, as a rule, allow a very large growth, as it was always the aim, as it should be in turning under cover or green manure crops provided the bulk of green material is considerable, to turn the crop under some little time previous to the date of planting the crop which is to follow.

Conclusions apparently justified at the End of the Period of Annual Application.

My conclusions, if based solely upon results obtained during the period of annual application of manure, must have been about as follows: —

1. The various tabulations which have been presented indicate wide variations, and do not justify sweeping conclusions as to the superiority of either one or the other of the two systems under comparison.

2. The general results, however, in my opinion, indicate quite clearly that there was considerably more wastage, which varied from year to year in amount, from manure applied to plots N than from that first piled and later spread on plots S.

3. I believe that the fact of such excess wastage from plots N would have been brought out more distinctly by comparison of results had the rate of application of manure been lower, for the results afford fairly conclusive evidence that even after such wastage as occurred the amounts

of plant food remaining in the manure applied during the winter were in many cases at least sufficient to give the maximum yields possible under the other conditions affecting the crop.

4. I believe that our results indicate that conclusions based upon relative results of the two systems of applying manure compared for a single year or for a short series of years in current farm practice are in many cases unreliable because of the fact that the rate of application has often been sufficient so that even after such losses as occurred the supply of plant food was adequate for the crop under the conditions under which it was grown.

5. Whether the results of the comparisons made would have been similar on land more nearly level is a question on which I am able simply to express a general opinion. That opinion, based upon extensive opportunities for observation of conditions existing on Massachusetts farms, is that in almost all parts of the State there is sufficient slope to the land under cultivation so that some wash over the surface during winter and consequently some transfer of soluble plant food or absolute waste must usually be expected.

Relative Lasting Effects of Winter and Spring Applications.

Manure having been applied annually, with the exception noted, under the two systems compared from 1900 to 1911, inclusive, it was thought best to continue cropping the plots for a series of years without further differing application of either manure or fertilizer to plots N and S. As a matter of fact, the only applications made to any of the plots during the period 1912–19, both inclusive, were dressings of lime applied in 1914 and again in 1917 at the rate of 1,866 pounds per acre of calcium and magnesium oxides. Different forms of lime were used on each of the plots 1, 2, 3 and 5, namely, plot 1, hydrated lime, plot 2, marl, plot 3, fine-ground limestone, and plot 5, limoid. In each case both the form and quantity of lime applied to the two halves of the original plots (N and S) were precisely the same. It would therefore seem that the lime applied cannot have any immediate bearing upon the comparison of the lasting effects of the two systems of applying manure previously used.

The crops grown in the different years now to be considered, and the yields on the several plots, are shown in Table VIII.

It will be noted that the yields on plots S are in general considerably greater than on plots N. The percentage averages for the five plots in the different years, the yields on plots N being taken as 100, are shown in Table IX, also the relative percentage standing of N and S for the several plots.

TABLE VIII. — *Yields per Acre, 1912–1919.*

Year.	Crop.	Plot 1.		Plot 2.		Plot 3.		Plot 4.		Plot 5.	
		North.	South.	North.	South.	North.	South.	North.	South	North.	South.
1912	Mixed grass and clover (pounds),	5,857	6,391	5,679	7,618	6,114	6,569	4,946	5,144	6,866	6,984
1913	Mixed grass and clover (pounds),	4,776	5,698	4,808	5,105	4,373	4,511	3,680	3,700	5,203	4,887
1914	Soy beans (ensilage) (pounds),	13,395	13,989	13,870	13,605	10,162	9,612	9,331	9,169	10,008	10,867
1915	Soy beans, Beans (bushels),	29.9	32.5	27.3	32.7	26.3	33.7	28.0	29.7	34.2	36.3
	Soy beans, Straw (pounds),	2,541	2,427	2,376	2,494	2,075	2,642	2,271	2,275	3,061	3,357
1916	Corn, Grain (bushels),	53.3	67.2	44.1	62.7	36.7	64.7	44.7	51.7	60.7	56.8
	Corn, Stover (pounds),	3,463	4,650	2,849	4,828	2,275	4,393	2,236	3,680	4,432	5,303
1917	Corn, Grain (bushels),	37.6	58.4	37.8	49.9	28.7	51.0	39.1	45.3	56.7	51.9
	Corn, Stover (pounds),	2,790	4,551	2,078	3,957	1,919	3,878	2,770	3,621	4,333	4,690
1918	Mixed grass and clover (pounds),	2,572	3,265	3,245	3,324	3,166	2,711	2,117	2,623	2,691	4,056
1919	Mixed grass and clover (pounds),	2,513	5,224	4,076	5,144	1,662	3,364	2,157	3,482	3,977	4,630

TABLE IX. — *Percentage Results.*

Year.	Crop.	Percentages for South Half (North Half = 100 Per Cent).					
		Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Average of Five Plots.
1912	Mixed grass and clover,	109 2	134 1	107.4	104.0	101.7	111 0
1913	Mixed grass and clover,	119.3	106 2	103 2	100 6	93.9	104.6
1914	Soy beans (ensilage),	104 4	98 1	94 6	98.3	108 6	100 8
1915	Soy beans, Beans,	108 9	120 1	128.1	105.8	106 0	113.2
1915	Soy beans, Straw,	95.5	105.0	127 3	100 2	109.7	107.0
1916	Corn, Grain,	127.8	146 3	185 1	118.5	93 5	126.6
1916	Corn, Stover,	134.3	169 5	193.1	164.6	119 6	149.8
1917	Corn, Grain,	164 5	140 2	192 0	124.8	91.8	128.4
1917	Corn, Stover,	163.1	190 4	202.1	130 7	108.2	149 0
1918	Mixed grass and clover,	126 9	102 4	85.6	124.3	150 7	115.9
1919	Mixed grass and clover,	207.9	126 2	202 4	161.5	116 4	151.8

The general percentage average for plots 1, 2, 4 and 5 for the entire period 1912–19, inclusive, N being taken as 100, is 122.3 for S, while for plot 3 a similar comparison shows the standing of S to be 138.2.

The figures presented in the different tables bring out the fact very clearly that the lasting effect of manure piled when taken to the field and spread in the spring is much greater than that of manure spread in the winter. For confirmation of the fact just stated, the reader should compare the figures given in Table IX with those in Tables VI and VII, which refer to the period during which manure was applied annually.

The figures for successive years presented in Tables VIII and IX indicate clearly that the superiority of plots S as compared with plots N as yet shows no signs of diminution. On the contrary, it is considerably greater during the later years of the period under consideration than in the earlier. This is most clearly shown in the last column of Table IX, which gives the percentage averages of the five plots; thus, for example, during the first and second years of the period under consideration, plots S in mixed grass and clover showed a percentage superiority of 111.0 and 104.6; in the last two years, 1918 and 1919, corresponding figures were 115.9 and 151.8. A similar relation is shown between the percentage advantage of plots S in 1915 as compared with 1914, soy beans being the crop; and in 1917 as compared with 1916, corn being the crop. This advantage in the case of the corn crop is less than with the others.

Effect of the Two Systems previously followed in the Application of Manure on Growth during the Early Part of the Season and the Maturing of the Crop.

From the very first year of the period under consideration, 1912–19, it was noticed that much earlier and more vigorous growth took place on plots S than on plots N. Whatever the crop, the superiority of S was clearly shown by better color and more rapid advancement. It would have been a matter of great difficulty to determine the difference in amount of growth made at any given period by measurement, but the field was under constant careful observation, and my own judgment I feel sure is accurate. When corn was the crop, I should say that by the last of June or the first of July the average height of the plants on plots S was some 3 or 4 inches greater than on plots N. When the field was in mixed grass and clover, the degree of superiority was in my judgment about the same, and indicated in inches would, I think, equal about 3 inches by the first of June. The earlier maturity of the crops on plots S also clearly indicates an earlier start and more rapid progress. This is shown most conclusively by the figures in Table X, showing the relative proportions of hard and soft corn at the time of husking.

Table X. — *Effect on Ripening Corn (Pounds per Plot).*

Plot.	1916.				1917.			
	North Half.		South Half.		North Half.		South Half.	
	Hard.	Soft.	Hard.	Soft.	Hard.	Soft.	Hard.	Soft.
1,	915	29	1,170	19	700	60	1,150	30
2,	745	35½	1,090	19	700	64	980	29
3,	605	45	1,120	25	505	75	970	60
4,	755	35	895	20	710	80	885	30
5,	1,055	20	985	20	1,115	30	1,025	25

It will be noted that plot 5 is an exception to the general rule that the proportion of hard corn is considerably greater on plots S than on plots N. A considerable number of my different experiments, confirmed, I believe, as a rule, by the experiments of others, indicates that the period of ripening is affected more by the supply of phosphoric acid in highly available form than by any other plant-food constituent. An excessive supply of potash or of nitrogen does not, I believe, favor early ripening, but quite the contrary, unless there be a very liberal supply of phosphoric acid. It seems to me highly probable that the relative high standing of plot N on 5 in the proportion of hard corn is connected with the fact, which is generally known, that the proportion of phosphoric acid in manure from horses is higher, as a rule, than in that from milch cows,

but I desire to point out that a little variation in level and character of soil from the north to south perhaps helps to account for the relatively high standing of N on plot 5.

We have yet, however, to consider how the superiority of S on the other plots, 1, 2, 3, and 4, can be accounted for. It seems to me possible that variation in humus content produced by the different methods of handling the manure and consequent differences in soil temperatures or in biological activities going on in the soil may to some extent have influenced the results. I believe, however, that more important than these is probably this fact, which, as was pointed out again and again by Paul Wagner in connection with his different experiments a considerable number of years ago, had an important connection with results.[1] Wagner pointed out that in northern latitudes optimum weather conditions for growth may exist during only a small proportion of the so-called growing season. This fact is generally recognized. All those familiar with agriculture in Massachusetts understand that, especially for crops flourishing at high temperatures and to a considerable extent for others also, weather conditions during some part of the growing season are unfavorable to rapid progress. It is often too wet or too dry, or it may be too cold, and rather exceptionally too hot when the high temperature is coincident with shortage in supply of moisture. When optimum weather conditions come, then the plant is capable of extremely rapid growth, provided the other factors essential for such growth exist, and among such other factors an abundant supply of plant food is one of the most important. Where the supply of plant food is comparatively low or meager the crop may become a good one if the weather and other conditions for growth are favorable throughout the greater part of the growing season, but, in proportion as the best of weather exists only a portion of the time, the crop will come to rapid maturity only where it finds a great abundance of food. Considerable wastage evidently occurred where the manure was spread in the winter. It is clear, therefore, that the supply of food, and hence this one among the several factors essential to rapid progress when the weather conditions are right was found in highest degree on plots S. It has long been recognized that the farmer or gardener who works his land intensively (under which term in this connection I refer particularly to an abundant supply of available plant food) is less unfavorably influenced by bad weather than the farmer or gardener whose soils are relatively low in available plant food or poorly worked.

The Relative Effects of the Two Systems on the Proportion of Clover in Mixed Mowings.

Whenever the plots used in this experiment were put into mowing, a mixture of timothy, red top and medium and alsike clovers was sown. The field was in mowing in 1912 and 1913, the first two years of the period under consideration, and it was noted that the proportion of

[1] Paul Wagner: Zur Kali-Phosphat-Düngung nach Schultz-Lupitz, Darmstadt, 1889, s. 18 u. a.

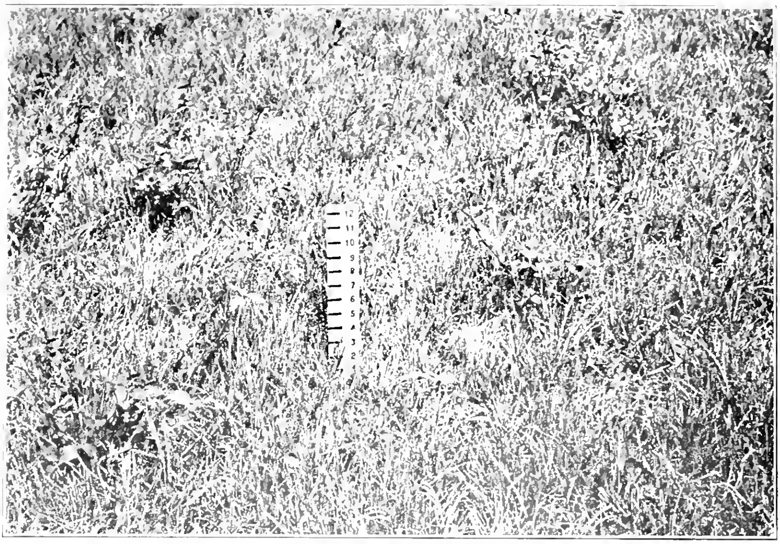


FIG. 1.—Plot 1, north half, from photograph taken Aug. 7, 1919.

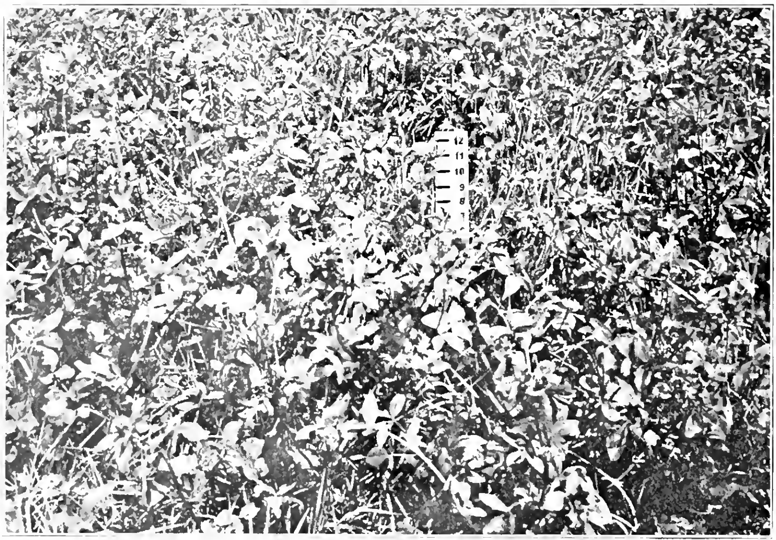


FIG. 2.—Plot 1, south half, from photograph taken Aug. 7, 1919.

clovers on plots S was considerably greater than on plots N. The distribution of clovers in the different plots was not entirely uniform, some variations being apparently due to differences in moisture conditions. No photographs were taken during these two years, and the fact stated is demonstrated principally by the greater superiority of the rowen crop (made up chiefly of clovers) on plots S than of the first crop on the same plots.

The plots were put into mowing again in 1918, the seed having been sown, as is customary in this part of the State and with the type of soil on which the experiments were located, in the standing corn about the time it was waist high in 1917. We have harvested the hay crops now for two years, and Figs. 1 and 2 were made from photographs taken on Aug. 7, 1919, by a station assistant, R. L. Coffin. The difference in the proportion of clover, it will be seen at once, is very striking. The proportions of grasses and clovers on different parts of the several plots were not entirely uniform either on single plots N and S, under comparison, or on different pairs, and the excess of clover was not as great everywhere as indicated by the illustrations.

With a view to indicating in words as clearly as possible the different conditions, notes were taken on June 17, 1918, by a very careful station assistant, Mr. R. L. Coffin. I quote from Mr. Coffin: —

Plot 1. N, very little clover, mostly red.
S, seven-eighths clover, red and alsike about evenly divided.

Plot 2. N, seven-eighths clover, mostly alsike, but more red than on plot 5.
S, over seven-eighths clover, practically a dense mass of clover, more red than alsike.

Plot 3. N, almost no clover, but a little both red and alsike present.
S, nearly seven-eighths clover, more red than alsike.

Plot 4. N, about one-fourth clover, mostly alsike; a little sorrel.
S, nearly seven-eighths clover, mostly alsike; a little sorrel. Growth on plot 4 not as heavy as on plot 5.

Plot 5. N, seven-eighths clover, mostly alsike.
S, a little more clover than on N. Except for two small areas, a dense mass of clover, mostly alsike.

General condition on all plots: heads just beginning to show on timothy and red top, the proportion of red top being apparently somewhat greater than that of timothy.

Why Clover has been more abundant on Plots S.

The facts which have been for a long time known concerning the proportions of the different leading plant-food constituents and their degree of solubility in manures appear to the writer to have indicated in advance the more important wastes likely to occur from manure spread during the winter and allowed to remain upon the surface. The more important of these facts which seem to have a bearing upon the results are as follows: —

In fresh, well-made cow manure the proportion of its nitrogen content soluble is about one-third of the whole; the proportion of its potash con-

tent soluble is about four-fifths of the whole; while practically all of the phosphoric acid is insoluble. In the case of the plots, then, to which cow manure was applied in winter, one must have anticipated that such waste as occurred would have carried off more potash than of either of the other more important elements. In the case of the stable manure applied to plot 5, as has already been pointed out, some fermentation had taken place before it was taken to the field. This must have increased the solubility of the nitrogen content, but this manure, it will be remembered, was from horses, and such manure is much drier than fresh cow manure, the urine being relatively far less abundant. This must, I think, decrease the probability of a loss of potash from manure spread during the winter. Moreover, the application made to plot 5 was usually comparatively late in the winter, so that the period of exposure on the surface was shorter than the average of the other plots, which also would tend to decrease the amount of such loss of potash as may have occurred.

It is now a matter of almost universal knowledge that the proportion of clover in mowings is much affected, throughout the greater part of the soils of Massachusetts at least, if not throughout those of the greater part of the northeastern section of the United States, by the supply of potash in available form; and the much greater proportion of clover on plots S than on plots N of 1, 2, 3 and 4 tends to confirm my opinion in a striking way, — that the greatest loss which occurred from manure spread upon the surface in the winter and allowed to remain there until spring was the loss of potash. The fact that there was less difference in the proportion of clover on N and S of plot 5 than on the other plots tends also to confirm the correctness of the opinion expressed concerning the losses from the partially fermented stable manure.

Just how great may have been the losses of nitrogen from manure spread in the winter and allowed to remain on the surface, our figures showing yields fail to give a very complete index; but the fact that in the eighth year without additional manure the yield of hay even on plots N was, in general, good shows that the wastage of nitrogen was probably not very excessive. Nor would excessive loss of this element, as a rule, be reasonably expected, in view of the fact that the manure spread in the winter on most of the plots was practically entirely unfermented, and could not under normal winter weather conditions undergo fermentation while lying upon the surface, which would increase the solubility of the nitrogen compounds found in the fresh manure.

Financial Results.

The basis of the calculations upon which the tables presenting relative financial results have been computed is as follows: Value of products per ton: millet hay, $10; mixed grass and clover hay, $12; rowen, $8; ensilage corn, $4; corn and soy bean mixture for ensilage, $4; soy beans for ensilage, $5; corn stover, $6; soy bean straw, $5. Value per bushel: corn, 70 cents (1 cent per pound on the ear); soy beans, $2.50. The

calculation was made on the basis of the average for the five pairs of plots N and S, and the area for which results are computed is 1 acre. The excess cost of handling manure where it was piled when hauled out and spread in the spring has been estimated at $2 per acre where the work is done upon a large scale, for on such scale the manure spreader would be used in applying the manure from the heaps in the spring, whereas conditions when manure is hauled out and applied during the winter are by no means always such in our climate as to make the use of the manure spreader practicable. It is believed, therefore, that the figure taken — $2 per acre — is sufficient to represent the difference in cost under conditions existing on farms of sufficient size to justify the use of the spreader.

The same values have been used in the calculations throughout the entire period covered by the two tables, although prices during the past four or five years have advanced materially, so that the figures taken as applied to these years are considerably too low. The reader will perhaps at once think that so also must be the figure representing the difference in the cost of handling the manure; but in this connection it is important to remember that during the past eight years no manure has been applied to any of the plots, so that the question of the excess cost of handling does not affect the results as presented in Table XII.

TABLE XI. — *Calculated Results per Acre for the Period of Annual Application of Manure.*

Crop.	Crop Values, Yearly Average. Difference in Favor of —		Cost of Application of Manure. Difference in Favor of —	Total Yearly Average. Difference in Favor of —		Number of Years.	Total Difference in Favor of —	
	Winter (N).	Spring (S).	Winter (N).	Winter (N).	Spring (S).		Winter (N).	Spring (S).
Millet,	-	$7 83	$2 00	-	$5 83	1	-	$5 83
Soy beans,	$1 20	-	2 00	$3 20	-	1	$3 20	-
Corn,	-	3 97	2 00	-	1 97	3	-	5 91
Mixed grass and clover,	-	66	2 00	1 34	-	5	4 70[1]	-
Corn (ensilage),	-	2 05	2 00	-	05	1	-	05
Corn and soy beans (ensilage).	25	-	2 00	2 25	-	1	2 25	-
Total,	-	-	-	-	-	12	$10 15	$11 79

Balance in favor of spring, $1.64.
Average for 1 year, $0.14.

[1] No manure applied in 1907; cost of applying deducted.

Examination of Table XI shows that there was a small financial advantage due to the larger crop in favor of plots S, which represent the double handling system. Table XII shows a much larger difference. There are two reasons for this: first, the superiority of plots S during the period subsequent to that covered by annual applications of manure was much greater than during the period in which manure was applied yearly; and, second, this superiority, as already pointed out, has shown a tendency to increase with lapse of time.

While it has previously been referred to, it seems desirable again to call attention to the fact that spreading manure during the winter helps to relieve the pressure of work in the spring, and therefore possesses some advantage which cannot be shown in dollars and cents, and which of course varies with the weather and other conditions affecting the spring work.

TABLE XII. — *Calculated Results per Acre (1912–19).*

Crop.	Crop Values, Yearly Average. Difference in Favor of Spring (Plots S).	Number of Years.	Total Difference in Favor of Spring (Plots S).
Mixed grass and clover,	$2 10	4	$8 40
Soy beans (ensilage),	24	1	24
Soy beans,	10 04	1	10 04
Corn,	12 73	2	25 46
Total,	-	8	$44 14

Average for 1 year, $5.52.

FINAL CONCLUSIONS.

1. Had the experiment been brought to a conclusion in 1911, the last year of the period during which manure was applied annually, the statement would apparently have been justified that it made little difference in financial result which of the two plans of applying manure should be followed. This, however, would not have amounted to a demonstration that excess wastage had not occurred on plots N, for the reason that in spite of such wastage under the conditions which had existed throughout the experiment, the supply of plant food on plots N had probably been adequate to give yields nearly as large as all the conditions affecting the yields on plots S made possible.

2. That the manure on plots N had suffered quite serious losses has been made apparent by the relative yields as compared with plots S during the period 1912–19, in which no additional manure had been applied.

3. There must have been considerable excess wastage on plots N, even had the rate of application been smaller, although, of course, the financial loss would have been less.

4. The conclusion which appears to me to be fully justified by the results obtained to date (1919) is that the manure for the crop of the following season should be incorporated with the soil by the plow or harrow after the removal of the crop in the late fall, if practicable, rather than spread upon the surface to remain until spring.

5. There can be little doubt that the excess wastage on plots N would have been less on land which was more nearly level than that used in this experiment, but the land surface in Massachusetts and throughout a large part of the New England States is so broken that the proportion of land so level that there is no wash over the surface is comparatively small.

6. The earlier start and more rapid growth on plots S, especially during the later years of the experiment, are a decided advantage, and in many cases go far to insure a superior crop on account of the fact that the moisture supply in the early part of the season is more surely adequate to the needs of the crop, as a rule, than later.

Yet in one other way the earlier start and more rapid growth which doubtless occur in the root system as well as in the tops help to insure a good crop. I would refer also to the fact that crops which develop early and rapidly are far more likely to escape serious injury by insect enemies than those starting late or growing slowly, both because better able to resist attacks of such enemies, and because capable of quickly replacing tissues which are eaten or injured. In the case of some parasitic diseases, also, the plant making an early start and rapid growth is less likely to be seriously injured.

7. The earlier maturity of the crop on plots S constitutes an important advantage in favor of such practice as will prevent excessive loss of plant food. This of course is particularly true of crops thriving at relatively high temperatures, such, for example, as Indian corn and soy beans.

8. There can be no doubt that there is some wastage of nitrogen from winter-spread manure, and nitrogen is, as a rule, the most costly of the different plant-food elements; but reduction of the amount of wastage of nitrogen through the practice of piling and spreading the manure to be immediately incorporated with the soil in the spring is not the only nitrogen advantage connected with that practice. Particular attention has been called to the far greater proportion of clover on plots S than on plots N. Under these relative conditions it appears certain that a much greater amount of nitrogen must be taken from the air, and either made

a part of the harvested portion of the crop or left behind in the stubble and roots, on plots S than on plots N, thus reducing materially the necessity for application of nitrogen to crops in later years.

Bibliography.

WM. P. BROOKS. Reports of the Progress of the Experiment. Hatch Experiment Station annual reports: 14, p. 48; 15, p. 145; 16, p. 147; 17, p. 147; 18, p. 32. Massachusetts Agricultural Experiment Station annual reports: 19, p. 54; 20, p. 55; 21, Pt. II, p. 36; 22, Pt. I, p. 44; 23, Pt. I, p. 48; 25, Pt. I, p. 32.

BULLETIN No. 197.

DEPARTMENT OF CHEMISTRY.

THE NUTRITIVE VALUE OF CATTLE FEEDS.

1. VELVET BEAN FEED FOR FARM STOCK.

BY J. B. LINDSEY AND C. L. BEALS.

Summary of Results with Suggestions.

1. Velvet bean feed consists of the ground seeds and pods of the velvet bean, a leguminous plant grown quite largely in the southern States.

2. In chemical composition it resembles wheat bran, but contains rather more fiber, due to the presence of the bean pods.

3. As a result of digestion studies it was found to contain about 130 pounds, or 11.5 per cent, more digestible organic nutrients per ton than does wheat bran, and as a component of the dairy ration one would expect somewhat better results from its use.

4. Two feeding experiments were made with groups of six and four cows, in which the ration consisted of hay and a grain ration of 20 per cent cottonseed meal, 40 per cent corn feed meal, and 40 per cent velvet bean feed or wheat bran. The results show that the cows while receiving the velvet bean ration produced 2.7 and 9 per cent, with an average of 5 per cent, more milk than while on the wheat bran ration. It seems safe, therefore, to conclude that the velvet bean feed is somewhat superior to wheat bran for dairy purposes.

5. It may constitute as high as 40 per cent of a dairy ration, together with a like amount of corn or hominy meal or ground oats, and some 20 per cent of cottonseed or linseed meal, or other high-grade protein concentrate.

6. As a food for pigs a ration composed by weight of 50 parts corn feed meal, 40 parts velvet bean feed, and 10 parts digester tankage

or one composed of equal weights of corn feed meal and velvet bean feed, did not prove as satisfactory as one composed of 90 parts corn feed meal and 10 parts digester tankage; and so large an amount of the velvet bean feed is not recommended.

7. A ration composed by weight of 20 parts velvet bean feed, 20 parts high-grade peanut meal, 50 parts corn meal, and 10 parts alfalfa meal gave as satisfactory results as one composed of 80 parts corn meal and 10 parts each of digester tankage and alfalfa meal; and such combinations are to be recommended.

8. The addition of 10 per cent ground alfalfa to the grain ration for growing pigs in order to supply the necessary vitamines did not seem to exert any marked effect in promoting growth.

9. As a feed for horses, velvet bean feed, if sufficiently dry to prevent decomposition, may comprise some 20 per cent of the grain ration, mixed together with 30 per cent oats, 40 per cent cracked corn and 10 per cent wheat bran.

10. It is important that the velvet bean feed should be well dried before being shipped, otherwise more or less decomposition is likely to set in, and the feed proves unsatisfactory for use. The writer regards a satisfactory quality of velvet bean feed as a distinct addition to the protein concentrates at the disposal of northern feeders.

11. Velvet bean meal (beans minus the pods) would undoubtedly prove more satisfactory for pigs and horses.

A. What Velvet Bean Feed is.

The velvet bean, of which there are many varieties, is a tropical legume, and is grown largely in Florida, Alabama and Mississippi. It needs a long season for its maturity, and is grown rarely north of Savannah. It is a rank grower, its vines trailing on the ground to a length of from 15 to 75 feet; they are difficult to cure for hay and have been used largely for grazing. It is now becoming common to pick the best of the beans and use them without hulling for cattle, or hulled as a food for pigs. The former is termed velvet bean feed, and the latter velvet bean meal. Machinery has more recently been devised for drying and grinding the unhulled beans, and it is said that the industry is increasing rapidly. About a year since, more or less of the velvet bean feed was placed upon the Massachusetts market, but it did not seem to give the best of satisfaction, partly on account of the feeders' lack of familiarity with the product, and partly because of its being shipped in too moist a condition.

Considerable has already been published relative to the velvet bean, particularly concerning its habitat, growth, adaptability to various soil

and climatic conditions, as well as its suitability as a pasture crop, source of roughage, its value as silage and as a soil renovator.[1] Such information has a more particular value for parties residing in those States where the plant can be grown advantageously. Several experiments are also on record describing the feeding value of the ground bean and pods, and one experiment on its digestibility.

Inasmuch as the velvet bean feed (pods and beans) may become distributed in Massachusetts, experiments were undertaken at this station, particularly with reference to its digestibility and its suitability as a food for dairy stock, pigs and horses.

B. Composition of Velvet Bean Feed.

	Number of Analyses.	Water.	Ash.	Protein.	Fiber.	Extract.	Fat.
Velvet bean feed,	3	11.31	4.57	16.66	12.71	50.66	4.09
Wheat bran (for comparison),	116	10.00	6.20	16.10	10.00	53.30	4.40

The feed resembles wheat bran in chemical composition. It has slightly more protein, considerably more fiber, due to the presence of the bean pods, and somewhat less extract matter than wheat bran.

C. Digestibility of Velvet Bean Feed.

Two duplicate experiments were made with two different pairs of sheep. Two sheep were fed daily 550 grams of hay and 250 grams of the bean feed, and two other sheep 600 grams of hay and 200 grams of the feed. The results of the trials giving the amounts of the several constituents digested (digestion coefficients) are here stated, but the details of the experiments will be published elsewhere.

Results (Digestion Coefficients).

Sheep.	Dry Matter.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.
XII,	82.06	41.48	76.64	81.07	89.71	86.69
XIII,	71.48	28.52	73.96	51.09	81.82	74.41
IX,	70.96	22.97	68.56	46.60	80.35	72.79
XI,	81.16	33.24	78.02	71.06	86.83	85.63
Average,	77	32	74	62	85	80
Average (Georgia station),[1]	79	58	74	64	77	86
Average (all results),	79	53	74	64	78	85
Wheat bran (for comparison),	66	–	77	39	71	63

[1] Farmers' Bulletins Nos. 300 and 962; Georgia Experiment Station Bulletin No. 129; Journal of Agricultural Research, Vol. XIII, No. 12, p. 611; Florida Experiment Station Bulletin No. 102.

Our own results with four sheep show some noticeable variations. Sheep XII and XI seem to have digested the feed better than the two other sheep. This variation is noticeable in each of the several ingredients. The average results agree quite closely with those secured by Ewing and Smith[1] with steers.

Applying the average coefficients to the chemical composition of the velvet bean feed we find 2,000 pounds of the material to contain the following: —

Digestible Organic Nutrients in 2,000 Pounds.

	Protein.	Fiber.	Extract Matter.	Fat.	Total.
Velvet bean feed, ...	246.6	162.6	790.2	69.54	1,268.94
Wheat bran (for comparison), .	248.0	78.0	756.8	55.40	1,138.20

Velvet bean feed contains about the same amount of digestible protein as does wheat bran. Its content of digestible fiber, extract matter and fat is somewhat in excess of that contained in the bran, and on the basis of total digestible organic nutrients it is shown to have some 11.5 per cent more feeding value than the latter feed.

D. Velvet Bean Feed for Cows.

During the fall and winter of 1918–19 two feeding experiments with velvet bean feed werq made with milch cows. In one case six and in the other four animals were used. They were divided into groups in each experiment, and were fed by the reversal method for periods of five weeks (besides preliminary periods) on a ration composed of hay for roughage and a grain mixture made up of 20 per cent cottonseed meal, 40 per cent corn feed meal (corn meal in second experiment), and 40 per cent of either velvet bean meal or wheat bran.

Before starting the experiment the cows were carefully chosen and paired off as well as possible in regard to age, breed, period of lactation, yield of milk, fat, etc.

The hay and grain rations were carefully calculated for each animal on the basis of milk and maintenance requirements according to the Haecker Standards.[2] The general care and management of the animals in no way differed from that always used in our feeding experiments, and require no discussion here. Hay and grain samples were taken at regular intervals, composited and analyzed. Milk samples were taken on the first, third and fifth weeks of each half of each experiment.

[1] P. V. Ewing and F. H. Smith in Journal of Agricultural Research, Vol. XIII, No. 12, p. 616. Results with five different steers in eighteen single trials.

[2] See Minn. Bul. No. 140, p. 56.

TABLE I. — *History of Cows.*

EXPERIMENT I.

Name.	Breed.	Age (Years).	Last Calf.	Served.	Beginning of Experiment.		
					Weight (Pounds).	Milk (Pounds).	Fat (Per Cent).
Samantha II,	Grade Holstein,	4	July 22, 1918,	- -	975	32	4.50
Peggy,	Grade Jersey,	8	Aug. 13, 1918,	- -	755	25	5.75
Red IV,	Grade Jersey,	5	Dec. 2, 1917,	June 2, 1918,	835	19	5.80
Samantha III,	Grade Holstein,	5	Aug. 26, 1918,	- -	1,140	30	4.60
Colantha III,	Grade Holstein,	4	Mar. 6, 1918,	June 12, 1918,	1,000	24	3.60
Fancy IV,	Grade Jersey,	4	July 22, 1918,	- -	700	21	4.63

EXPERIMENT II.

Name.	Breed.	Age (Years).	Last Calf.	Served.	Weight (Pounds).	Milk (Pounds).	Fat (Per Cent).
Samantha III,	Grade Holstein,	5	Aug. 26, 1918,	Dec. 5, 1918,	1,170	25	4.60
Fancy IV,	Grade Jersey,	4	July 22, 1918,	Oct. 30, 1918,	810	18	5.35
Colantha II,	Grade Holstein,	4	July 22, 1918,	Nov. 7, 1918,	1,050	30	4.25
Ida II,	Pure Jersey,	6	Oct. 27, 1918,	Dec. 9, 1918,	800	28	5.60

TABLE II. — *Total Amount and Average Daily Amount of Food consumed per Cow and per Ration (Pounds).*

EXPERIMENT I.

Velvet Bean Feed Ration.

Dates.	Cows.	Hay. Total.	Hay. Daily.	Velvet Bean Mixture. Total.	Velvet Bean Mixture. Daily.	Wheat Bran Mixture. Total.	Wheat Bran Mixture. Daily.
Oct. 1-Nov. 4, 1918,	Colantha II,	840.00	24.00	350.0	10.00	–	–
	Peggy,	697.75	19.94[1]	315.0	9.00	–	–
	Red IV,	665.00	19.00	245.0	7.00	–	–
Nov. 15-Dec. 19, 1918,	Samantha III,	840.00	24.00	315.0	9.00	–	–
	Colantha III,	735.00	21.00	280.0	8.00	–	–
	Fancy IV,	665.00	19.00	245.0	7.00	–	–
Totals,		4,442.75	–	1,750.0	–	–	–
Averages,		–	21.16	–	8.73	–	–

Wheat Bran Ration.

Dates.	Cows.	Hay. Total.	Hay. Daily.	Velvet Bean Mixture. Total.	Velvet Bean Mixture. Daily.	Wheat Bran Mixture. Total.	Wheat Bran Mixture. Daily.
Oct. 1-Nov. 4, 1918,	Samantha III,	840.00	24.00	–	–	315.0	9.00
	Colantha III,	735.00	21.00	–	–	280.0	8.00
	Fancy IV,	642.00	18.91[2]	–	–	245.0	7.00
Nov. 15-Dec. 19, 1918,	Colantha II,	840.00	24.00	–	–	350.0	10.00
	Peggy,	700.00	20.00	–	–	315.0	9.00
	Red IV,	665.00	19.00	–	–	245.0	7.00
Totals,		4,422.00	–	–	–	1,750.0	–
Averages,		–	21.15	–	–	–	8.73

EXPERIMENT II.

Velvet Bean Feed Ration.

Dates.	Cows.	Hay. Total.	Hay. Daily.	Velvet Bean Mixture. Total.	Velvet Bean Mixture. Daily.	Wheat Bran Mixture. Total.	Wheat Bran Mixture. Daily.
Dec. 30, 1918-Feb. 2, 1919.	Samantha III,	840.00	24.00	315.0	9.00	–	–
	Fancy IV,	665.00	19.00	245.0	7.00	–	–
Feb. 13-March 19, 1919,	Colantha II,	840.00	24.00	332.5	9.50	–	–
	Ida, II,	735.00	21.00	332.5	9.50	–	–
Totals,		3,080.00	–	1,225.0	–	–	–
Averages,		–	22.00	–	10.75	–	–

[1] Peggy left a total of 2.25 pounds of hay, or a daily average of .06 pound unconsumed.
[2] Fancy IV left a total of 3 pounds of hay, or a daily average of .09 pound unconsumed.

TABLE II. — *Total Amount and Average Daily Amount of Food consumed per Cow and per Ration (Pounds)* — Concluded.

EXPERIMENT II — *Con.*

Wheat Bran Ration.

DATES.	COWS.	HAY.		VELVET BEAN MIXTURE.		WHEAT BRAN MIXTURE.	
		Total.	Daily.	Total.	Daily.	Total.	Daily.
Dec. 30, 1918–Feb. 2, 1919.	Colantha II, .	840.00	24.00	–	–	332.5	9.50
	Ida II, . .	735.00	21.00	–	–	332.5	9.50
Feb. 13–March 19, 1919,	Samantha III,	840.00	24.00	–	–	315.0	9.00
	Fancy IV, .	665.00	19.00	–	–	245.0	7.00
Totals, . . .	. . . . .	3,080.00	–	–	–	1,225.0	–
Averages, . .	. . . . .	–	22.00	–	–	–	10.75

TABLE III. — *Analysis of Feeds (Per Cent).*

EXPERIMENT I.

FEED.	Average Moisture.[1]	Dry Matter.[1]	DRY MATTER. Ash.	Protein.	Fiber.	Extract Matter.	Fat.
Hay, ...	12.17	87.83	6.18	8.70	30.57	51.72	2.83
	10.50	89.50					
Velvet bean mixture, .	11.31	88.69	4.08	20.56	11.42	56.12	7.82
	9.72	90.28					
Wheat bran mixture, .	11.37	88.63	5.23	19.09	10.71	56.59	8.38
	10.32	89.68					

EXPERIMENT II.

FEED.	Average Moisture.[1]	Dry Matter.[1]	Ash.	Protein.	Fiber.	Extract Matter.	Fat.
Hay, ...	14.00	86.00	5.89	7.48	29.74	54.41	2.48
	12.70	87.30					
Velvet bean mixture, .	11.19	88.81	4.00	19.22	9.22	63.20	4.36
	10.24	89.76					
Wheat bran mixture, .	11.46	88.54	4.85	18.32	8.44	63.34	5.05
	10.27	89.73					

[1] The two figures in each case represent the average of three samples taken in each half of the trials.

TABLE IV. — *Total and Average Daily Amount of Dry Matter consumed in Each Ration.*

EXPERIMENT I.

Velvet Bean Ration.

Dates.	Hay. Total.	Hay. Daily.	Grain. Total.	Grain. Daily.	Grain. Total.	Grain. Daily.
Oct. 1–Nov. 4, 1918, Nov. 15–Dec. 19, 1918,	3,940	18.76	1,566	7.46	-	-

Wheat Bran Ration.

Dates.	Hay. Total.	Hay. Daily.	Grain. Total.	Grain. Daily.	Grain. Total.	Grain. Daily.
Oct. 1–Nov. 4, 1918, Nov. 15–Dec. 19, 1918,	3,938	18.75	-	-	1,561	7.42

EXPERIMENT II.

Velvet Bean Ration.

Dates.	Hay. Total.	Hay. Daily.	Grain. Total.	Grain. Daily.	Grain. Total.	Grain. Daily.
Dec. 30, 1918–Feb. 2, 1919, Feb. 13–March 19, 1919,	2,669	19.06	1,894	7.81	-	-

Wheat Bran Ration.

Dates.	Hay. Total.	Hay. Daily.	Grain. Total.	Grain. Daily.	Grain. Total.	Grain. Daily.
Dec. 30, 1918–Feb. 2, 1919, Feb. 13–March 19, 1919,	2,668	19.05	-	-	1,091	7.79

In each experiment the two rations contained the same amount of dry matter.

TABLE V. — *Average Dry and Digestible Nutrients in the Average Daily Ration (Pounds).*

EXPERIMENT I.

Ration.	Dry Matter.	Digestible Nutrients. Protein.	Fiber.	Extract Matter.	Fat.	Total.[1]	Nutritive Ratio.
Velvet bean,	26.22	2.05	3.89	9.51	.77	16.22	1:7.4
Wheat bran,	26.18	1.97	3.74	9.24	.76	15.71	1:7.4

[1] Including fat multiplied by 2.2.

TABLE V. — *Average Dry and Digestible Nutrients in the Average Daily Ration (Pounds)* — Concluded.

EXPERIMENT II.

Ration.	Dry Matter.	Digestible Nutrients.					Nutritive Ratio.
		Protein.	Fiber.	Extract Matter.	Fat.	Total.	
Velvet bean, . .	26.87	2.24	3.87	11.87	.59	18.58	1:7.6
Wheat bran, . .	26.84	1.86	3.63	10.29	.53	16.31	1:8.1

The velvet bean ration contained rather more digestible matter than the wheat bran ration.

TABLE VI. — *Gain or Loss in Live Weight (Pounds) per Herd.*

Ration.	Experiment I.		Experiment II.		Total.
	Gain.	Loss.	Gain.	Loss.	
Velvet bean meal, ...	81	34	28	2	+73
Wheat bran, ...	135	0	32	8	+159

In the two experiments the cows when receiving the wheat bran ration seemed to gain a little more in weight than when receiving the velvet bean ration.

TABLE VII. — *Yield of Milk and Milk Ingredients.*

EXPERIMENT I.

Velvet Bean Ration.

Dates.	Cows.	Milk (Pounds).	Solids.		Fat.	
			Per Cent.	Pounds.	Per Cent.	Pounds.
Oct. 1–Nov. 4, 1918, .	Colantha II, .	1,218.9	12.50	152.36	4.07	49.61
	Peggy, . .	885.8	14.89	131.90	6.30	55.81
	Red IV, . .	724.6	15.28	110.72	5.99	43.40
Nov. 15–Dec. 19, 1918,	Samantha III,	905.8	13.09	118.57	4.39	39.76
	Colantha III, .	830.8	12.67	105.26	3.83	31.82
	Fancy IV, .	672.0	13.82	92.87	5.21	35.01
Totals, ...	. . . . .	5,237.9	-	711.68	-	255.41
Averages, . . .	. . . . .	-	13.59	-	4.88	-

TABLE VII. — *Yield of Milk and Milk Ingredients* — Concluded.

EXPERIMENT I — *Con.*

Wheat Bran Ration.

Dates.	Cows.	Milk (Pounds).	Solids.		Fat.	
			Per Cent.	Pounds.	Per Cent.	Pounds.
Oct. 1-Nov. 4, 1918,	Samantha III,	948.7	12.89	122.30	4.47	42.41
	Colantha III,	796.0	12.47	99.26	3.90	31.04
	Fancy IV,	739.7	13.80	102.08	5.10	37.72
Nov. 15-Dec. 19, 1918,	Colantha II,	1,163.0	12.69	147.58	4.01	46.64
	Peggy,	831.8	15.54	129.26	6.44	53.57
	Red IV,	620.5	16.14	100.15	6.47	40.15
Totals,		5,099.7	-	700.63	-	251.53
Averages,		-	13.74	-	4.93	-

EXPERIMENT II.

Velvet Bean Ration.

Dates.	Cows.	Milk (Pounds).	Solids Per Cent.	Solids Pounds.	Fat Per Cent.	Fat Pounds.
Dec. 30, 1918-Feb. 2, 1919.	Samantha III,	763.8	13.49	103.03	4.64	35.44
	Fancy IV,	596.0	14.70	87.61	5.32	31.70
Feb. 13-March 19, 1919,	Colantha II,	1,260.0	13.40	168.84	4.51	56.82
	Ida II,	827.6	14.81	122.86	5.81	48.19
Totals,		3,447.4	-	482.34	-	172.15
Averages,		-	13.99	-	4.99	-

Wheat Bran Ration.

Dates.	Cows.	Milk (Pounds).	Solids Per Cent.	Solids Pounds.	Fat Per Cent.	Fat Pounds.
Dec. 30, 1918-Feb. 2, 1919.	Colantha II,	995.8	13.03	129.75	4.33	43.31
	Ida II,	862.9	14.74	127.19	5.85	50.47
Feb. 13-March 19, 1919,	Samantha III,	749.7	13.51	101.28	4.69	35.16
	Fancy IV,	556.3	14.51	80.71	5.38	29.92
Totals,		3,164.7	-	438.93	-	158.86
Averages,		-	13.87	-	4.99	-

In the first experiment an increase in milk yield of 2.7 per cent was secured, and in the second experiment an increase of 9 per cent, both in favor of the velvet bean ration.

In both experiments the velvet bean ration yielded 8,685.3 pounds, and the wheat bran ration 8,264.4 pounds, of milk, an average increase of 5 per cent in favor of the velvet bean ration.

In case of the velvet bean ration 100 pounds of dry matter produced 130 pounds of milk, and in case of the wheat bran ration, 125 pounds.

It seems evident, therefore, on the basis of digestibility and feeding experiments with dairy cows, that the velvet bean feed is somewhat superior as a dairy feed to wheat bran.

E. Velvet Bean Feed for Pigs.

Observations with two lots of pigs were made, the first in 1918 and the second in 1919.

Experiment I. — *August 12–November 20.*

Six pigs having reached a weight of about 50 pounds each were divided into three lots of two each, and fed on the following rations: —

Lot I. — Mixture by weight of 80 parts corn feed meal, 10 parts alfalfa meal and 10 parts digester tankage.

Lot II. — Mixture by weight of 50 parts corn feed meal, 40 parts velvet bean feed and 10 parts alfalfa meal.

Lot III. — Mixture by weight of 50 parts corn feed meal and 50 parts velvet bean feed.

The mixture fed to Lot I was considered a standard or check ration. That fed to Lots II and III was intended to demonstrate the efficacy of velvet bean feed in place of the tankage. Alfalfa was used in one ration and omitted in one to note if it aided, because of its "vitamine" content, in promoting growth.

Method of Feeding. — Ten ounces of each mixture were added to each quart of water to satisfy appetite. The grain mixture was at first mixed with a little cold water to convert it into a paste, then very hot water added, and the slop fed milk warm. The pigs were fed three times daily.[1]

Housing. — Each lot of pigs was kept in an outdoor pen, protected from rain and sun, and given the run of a small yard.

Weighing. — Each pig was weighed weekly on Monday morning before feeding.

---

[1] An ash mixture composed of 20 per cent salt, 40 per cent rock phosphate, 10 per cent ground limestone and 30 per cent wood ashes was kept constantly before the pigs in all of the experiments here described. The pigs also had access to charcoal.

Record of Feeds consumed and of Growth (Pounds).

Pigs.	Days.	Dry Matter in Feeds consumed.					Growth.				Dry Matter required to produce 100 Pounds Live Weight.
		Corn Feed Meal.	Alfalfa.	Tankage.	Velvet Bean Feed.	Total.	Weight at Beginning.	Weight at End.	Total Gain.	Daily Gain.	
1	101	344.2	41.7	36.5	-	422.4	52.5	180.5	128.0	1.27	330
2, ...	98[1]	320.2	38.8	34.3	-	393.4	57.5	182.5	125.0	1.27	315
3, ...	62	90.5	18.0	-	72.3	180.8	47.5	80.5	33.0	.53	548
4, ...	101	179.3	35.6	-	143.2	358.1	49.5	118.0	68.5	.68	523
5, ...	72	119.2	-	-	119.1	238.3	44.2	83.5	39.2	.55	600
6, ...	72	115 1	-	-	114.9	230 0	52.2	82.5	30.2	.42	795

[1] Sick for three days.

Pigs 1 and 2 had the advantage in that they were fed corn meal and skim milk when very young. Pigs 3, 4, 5 and 6 were fed different grain mixtures when too young and did not get as good a start. Pig 3 was badly out of condition and did not recuperate until August. Pigs 1 and 2 were normal in every way, and on the diet of corn feed meal and digester tankage for 101 days gained daily 1.27 pounds and produced 100 pounds of live weight for 322 pounds of dry matter fed. Pigs 3 and 4, on the diet of corn feed meal, velvet bean feed and alfalfa, and pigs 5 and 6, on a corn feed and velvet bean feed diet, gained noticeably less. All appeared healthy during the experiment, and ate well. Pigs 5 and 6 did not grow quite as well as pigs 3 and 4, and did not appear to be building out as good a framework. It seemed evident that the alfalfa was furnishing something in promoting early growth that was lacking in the diet fed pigs 5 and 6.

Although the experiment was not as satisfactory as one could wish, it at least indicated that so large an amount of velvet bean feed was not desirable in the daily diet, and that it was not a satisfactory substitute for digester tankage.

Experiment II. — June 9–November 1.

Six pigs, grade Chester White, weighing from 24 to 34 pounds each, were divided into lots of two each and fed on three different rations, two of which contained 20 per cent velvet bean feed in order to test its efficacy as a component of a grain mixture.

Lot I received by weight a mixture of 80 pounds of corn meal, 10 pounds of digester tankage and 10 pounds of ground alfalfa.

Lot II received by weight a mixture of 50 pounds of corn meal, 20 pounds of peanut meal, 20 pounds of velvet bean feed and 10 pounds of alfalfa meal. On July 8 the corn meal was increased to 60 pounds, the alfalfa eliminated and different kinds of green material fed from day to day.

Lot III received by weight a mixture of 60 pounds of corn meal, 20 pounds of peanut meal and 20 pounds of velvet bean feed.

Lot I, therefore, received the so-called standard or check ration, Lot II the velvet bean ration plus alfalfa meal or green material to assist in promoting growth, while in the case of Lot III this was omitted. From September 7 to September 20 coconut meal was substituted for the velvet bean feed because of lack of supply of the latter. The method of feeding, housing and weighing was the same as in Experiment I.

Record of Feeds consumed and of Growth (Pounds).

Pigs.	Days.	Dry Matter in Feeds consumed.						Growth.				Dry Matter required per 100 Pounds of Gain.
		Corn Meal.	Peanut Meal.	Velvet Bean Feed.	Digester Tankage.	Alfalfa Meal.	Total.	Weight at Beginning.	Weight at End.	Total Gain.	Daily Gain.	
1,	175	476.5	-	-	62.9	60.6	600.0	22	185	163	.93	368.1
2,	175	476.5	-	-	62.9	60.6	600.0	30	195	165	.94	365.0
3,	175	344.6	124.5	119.6[1]	-	4.4	593.1	27	162	135	.77	439.3
4,	175	344.6	124.5	119.6[1]	-	4.4	593.1	25	189	164	.94	361.6
5,	175	347.7	124.0	119.1[1]	-	-	590.8	34	185	151	.86	391.3
6,	175	347.7	124.0	119.1[1]	-	-	590.8	27	173	146	.83	404.6

[1] Includes 21.4 pounds of coconut meal.

Each of the pigs remained in a thrifty condition during the entire experiment, and from their looks one would not be able to say that one ration was proving more effective than another.

Lot I, receiving the corn and tankage mixture, made an average daily gain of .93 pound each, and required 366 pounds of dry matter to make 100 pounds of gain. An average for pigs of this size is .9 pound of gain daily, and a requirement of 377 pounds of dry matter per 100 pounds of gain.

Lot II, receiving the corn, velvet bean, peanut and ground alfalfa, made an average daily growth of .85 pound each, and required 400 pounds of dry matter for 100 pounds of gain. Pig 4 of this lot gained fully as well as either of the two pigs in Lot I, but for some reason, due perhaps to individuality, pig 3 made somewhat less daily gain.

Lot III, receiving substantially the same ration as Lot II, with the exception of the alfalfa, made an average daily gain of .85 pound each,

and required 398 pounds of dry matter per 100 pounds of gain. This latter lot did not do quite as well as Lots I and II, indicating possibly that the lack of alfalfa may have slightly checked growth, but the difference was so slight as not to warrant one in drawing any positive conclusions. The combination of corn meal, alfalfa, velvet bean feed and peanut meal gave as satisfactory results as corn meal and tankage, and indicates that some 20 per cent of velvet bean feed, when properly combined, can be used as a component of the ration for growing pigs.

A ration containing 40 to 50 per cent of velvet bean feed together with corn meal (Experiment I) proved unsatisfactory and its use in such amounts is not recommended.

F. Velvet Bean Feed for Horses.

Velvet bean feed of good quality was fed to two farm horses for a period of three months, comprising some 18 per cent of the daily grain ration, which was as follows: —

Grain Mixture.

	Pounds.
Oats,	100
Corn,	140
Wheat bran,	40
Velvet bean feed,	60

The horses received from 17 to 20 pounds daily of the mixture, did regular farm work and maintained their live weight. Velvet bean feed, if dry and free from mold, can be used in the amounts indicated with safety.[1]

Velvet bean meal (beans minus pods) would undoubtedly prove better suited as a feed for pigs and horses.

[1] For a fuller report, see Bulletin No. 188, pp. 259-262.

BULLETIN No. 198.

DEPARTMENT OF CHEMISTRY.

STUDIES OF CRANBERRIES DURING STORAGE.

CHEMICAL STUDIES.

BY F. W. MORSE AND C. P. JONES.

Chemical Changes in Cranberries in Storage.

For several years the Massachusetts Agricultural Experiment Station has been studying problems connected with the storage and shipment of cranberries, during the course of which chemical data have been gathered that are here arranged to show the composition of a few well-known varieties of cranberries and some of the changes which take place in their composition while they are held in storage.

The essential qualities of a fruit that is to be used for cooking or dessert are juiciness and flavor. With our present knowledge of analytical chemistry such qualities can be measured only in terms of water, sugar and acid, since as yet there are no sure methods for determining the characteristic fruit flavors or esters. Therefore determinations of water, total sugar and total acid were made in all our samples of cranberries, while the proximate analysis of the food constituents was executed on some of them.

The analyses of varieties have been selected as far as possible to show them at their best. The Early Black and the Howes varieties were sampled in October from lots stored at natural temperatures, while the McFarlin and Centennial varieties were sampled in November from lots in cold storage. Early Black is the earliest variety shipped from the Cape Cod district. It is of good quality, but is not a good keeper. Howes is a later variety and forms the main crop on many of the bogs. It is a good keeper, but is not equal to some other varieties in quality. The other two varieties are rated among growers as "fancy" kinds, and are grown in limited quantities. The McFarlin is an excellent variety in quality, but not as good a keeper as Howes. The Centennial is a very large berry, attractive on account of its size, of good flavor, but not as juicy as the others. Cranberries, however, are not sold under their variety names, like apples, but

usually bear brands, originated by the sales organizations, which are unrelated to the varieties.

Two lots of Wisconsin cranberries were sent to the laboratory from that State by Dr. N. E. Stevens. One variety was the well-known McFarlin, and the other was a fancy western variety, of attractive size and color, called Searl's Jumbo. The sugar content was a bit inferior to our Cape varieties in both samples, but the fruit was sent by parcel post in tight packages, and was probably in warm mail cars and rooms while in transit. Such conditions induce a somewhat rapid change in sugar content, as shown by our storage experiments.

The composition of the varieties is shown in the following table: —

TABLE I. — *Composition of Varieties of Cranberries in October.*

Variety.	Water.	Total Sugar.	Total Acid.
Early Black,	87.86	4.12	2.45
Howes (two lots),	87.44	3.95	2.31
McFarlin,	88.74	4.08	2.12
Centennial,	87.16	5.59	2.05
Searl's Jumbo (Wisconsin),	89.25	3.48	2.61
McFarlin (Wisconsin),	88.47	3.75	2.49

Proximate Food Constituents.

Variety.	Dry Matter.	Ash.	Protein.	Fiber.	Ether Extract.	Nitrogen-free Matter.
Howes,	12.23	.15	.35	1.51	.97	9.25
McFarlin,	11.26	.16	.35	1.18	.57	9.00
Centennial,	12.84	.17	.28	1.15	.51	10.73

It has been noted that the cranberries undergo some change in composition during the storage period, although they remain firm and sound, with no evidence of decay. The change is most pronounced when the fruit is held at the higher temperatures of storage in a warm room, and is barely noticeable at cold-storage temperatures just above the freezing point.

In the fall of 1917 changes in the fruit during storage were studied by the analysis of berries kept in the storehouse at the cranberry bog. Fruit of the Howes variety was sent to the laboratory at monthly intervals directly from the storehouse, by express or parcel post, in small, ventilated crates holding about 8 quarts. The first lot was shipped in October, soon after the fruit had been stored, and the final lot in February. No attempt

was made to ascertain the shrinkage in weight of the fruit during storage, since berries were all the time decaying, and no lot of selected fruit would fail to have more or less rotten berries in a week's time, and such berries lose water more rapidly than sound ones. To have correctly determined losses in weight of sound fruit over a period of months would have required the individual weights of a large number of berries, so that decayed berries could be rejected as they developed, and only sound berries weighed individually at the end of a given period. The chemical analyses included determinations of water, total sugar and total acid.

In 1918 the work was repeated in a similar manner with samples from the bog storehouse. In addition, several lots of cranberries were placed in the cold-storage rooms of the Horticultural Department about the middle of October, and samples were analyzed at intervals to compare their rate of change with the changes in the cranberries kept at the bog. The cold-storage house was built especially for fruit storage, and the fruit in it is held almost constantly just above 0° C. (32° F.).

The composition of the berries under different conditions of storage is shown in Table II.

TABLE II. — *Composition of Cranberries in Storage, 1917–19.*

	Dry Matter.	Total Sugar.	Total Acid.
Howes Variety.			
Storehouse: —			
Oct. 5, 1917,	12.89	3.97	2.28
Oct. 17, 1917,	-	3.85	-
Oct. 31, 1917,	11.81	-	-
Dec. 3, 1917,	11.58	3.27	2.32
Jan. 3, 1918,	11.76	3.47	2.37
Jan. 28, 1918,	11.78	3.58	2.26
Oct. 16, 1918,	12.23	3.93	2.34
Nov. 21, 1918,	12.06	4.19	2.15
Dec. 19, 1918,	12.10	4.18	2.01
Cold storage: —			
December, 1918,	12.14	4.04	1.96
January, 1919,	12.50	3.89	2.14
February, 1919,	12.54	3.72	2.17
McFarlin Variety.			
Cold storage: —			
November, 1918,	11.26	4.08	2.12
January, 1919,	11.59	4.09	2.12
Centennial Variety.			
Cold storage: —			
November, 1918,	12.84	5.59	2.05
January, 1919,	13.11	5.54	2.08

The samples for analysis invariably consisted of the firm, hard berries, with no evidence of decay. Some of the analytical results make it appear possible that selected lots of berries like these do not necessarily show progressive changes in composition for the average fruit of the early part of the season, but that the later berries are resistant to decay by less active cell organization and lower rate of metabolism.

In 1917 the Early Black cranberries picked from the little bogs at the Experiment Station were sampled and analyzed on September 25, soon after picking. The remainder was divided into two portions, one of which was placed in a refrigerator, and the other was left on a shelf in the basement at a temperature a little above the outside air on the average. These lots were sampled and analyzed four weeks later. The two lots were then allowed to stand until January, 1918, when the refrigerator lot was freed from all soft berries and sampled; while the lot from the basement was divided into two portions, one consisting of firm, sound berries, and the other, while free from rotten fruit, consisting of berries that were soft and rubber-like in physical appearance. Analyses of these lots of berries showed some striking differences.

Table III. — *Composition of Early Black Cranberries under Different Conditions of Storage.*

	Total Solids.	Total Sugar.	Total Acid.
Recently picked, September 25,	12.14	4.12	2.45
Two weeks later, October 8,	–	4.48	2.36
From refrigerator, October 23,	–	4.17	2.49
From basement, October 23,	–	3.99	2.43
From refrigerator, January,	11.01	3.51	2.35
From basement, January, firm,	10.59	2.62	2.55
From basement, January, soft,	11.76	2.75	2.63

The character of the package in which cranberries are stored and shipped has been closely related to changes in the properties of the fruit. In the course of storage investigations, made to determine the causes of cranberry spoilage after harvesting, Shear and Stevens observed a considerable number of berries that were soft, but which contained no organisms of decay.[1] Since the more thoroughly oxygen was excluded from the fruit the larger the quantity of softened berries, the trouble appeared to be caused by the lack of ventilation, and the berries were regarded as asphyxiated.

In December, 1917, Dr. Stevens brought to the laboratory directly

[1] Proc. Amer. Cranberry Growers' Assoc. 48 (1917), pp. 6–9. Mass. Agr. Expt. Sta. Ann. Rept. 30 (1918), pp. 235–239.

from Washington several lots of Howes berries that had been stored in small cans from which the air had been displaced by carbon dioxide gas. The fruit had been held in these cans for two months at different temperatures, viz., 0°, 5°, 15° and 20° C. (32°, 41°, 59° and 68° F.). Some berries at each temperature still remained firm and sound, although at 20° C. there were not enough for a satisfactory analysis. The softened berries had been attacked by the end rot fungus in most cases, but from the lot held at 0° C. enough typically asphyxiated berries were secured for chemical examination. The analyses of the sound berries showed a slightly lower sugar content at the higher temperatures, with practically no changes in water and acidity. The asphyxiated berries, although kept at the lowest temperature, contained much less sugar than any of the sound berries, indicating a much more destructive action on the fruit sugar when oxygen was lacking.

TABLE IV. — *Howes Cranberries stored at Fixed Temperatures.*

	Water.	Total Sugar.	Total Acid.
Sound berries at 0° C.,	88.30	3.56	2.25
Sound berries at 5° C.,	88.29	3.51	2.29
Sound berries at 15° C.,	88.45	3.37	2.24
Asphyxiated berries at 0° C.,	–	2.38	2.40

A small sample of asphyxiated berries with but little evidence of rot about them was selected from the combined lots stored at 15° and 20° C. The determination of sugar in this sample showed but 2.04 per cent.

It is a common practice in the household to preserve cranberries by sealing them in jars filled with water. One experiment was tried to determine the effect of such treatment on the composition of the fruit.

Two fruit jars were filled with cranberries from the lot of Howes received from the Experiment Station bog in October. Distilled water was added to the jars until they were brimful, when the covers were put on and clamped as in canning fruit. The jars were set away in a cool room and allowed to remain until February. When the jars were opened the water was found to contain carbon dioxide which escaped in bubbles as soon as the pressure on the covers was released. The fruit showed no signs of rot, but every berry was softened and felt like rubber. The water contained acid, sugar and coloring matter that had diffused from the fruit. The berries contained 10.36 per cent dry matter, 2.85 per cent sugar and 1.87 per cent acid, — quantities considerably less than in the same kind of berries stored in a cool room. While decay had been prevented, the absence of air had produced results similar to the asphyxiated fruit previously described.

The results of these different experiments show a steady loss of sugar

by cranberries during storage, and this loss is greater at the higher temperatures, while the destruction is further accelerated by a lack of air. The total acidity changes were very little, hence on account of its high proportion in cranberries they do not lose flavor on long keeping as noticeably as some other fruits.

Respiration of Cranberries.

The percentage changes in the composition of fruits produced by different storage temperatures throw little light on the real rate of change at a given temperature. A simple method of estimating the rate of chemical change in fruit at any given temperature is to determine the amount of carbon dioxide exhaled by a definite weight of the fruit in an hour. The carbon dioxide is produced by respiration of the fruit, just as it is produced in animals by the same action. The oxygen of the air penetrates the cells [1] of the fruit and unites with some of the matter in the cells, apparently the sugar, and forms carbon dioxide and water which are exhaled. There is no appearance of rhythmical action, as in the breathing of animals, but the exhalation of the carbon dioxide and water can be readily determined by chemical means.

Respiration experiments with several kinds of fruits [2] have been reported, and it has been shown that respiration varies noticeably with changes in the temperature of the fruit.

Respiration experiments with cranberries were carried out during two seasons, 1917–18 and 1918–19. One kilogram of cranberries was used in nearly every case, and whenever possible for convenience in calculation. The berries were carefully hand-sorted before weighing the desired quantity, in order to avoid any berries which had begun to rot. It was impracticable to hold the cranberries closely to a given degree of temperature during a run, and it was found necessary to maintain them for several hours before a run as closely as possible to the temperature desired to be tried in the respiration chamber, because the internal temperature of the berries was slow to adjust itself to that of the chamber if they were far apart, and the exhalation of carbon dioxide might be too high or too low accordingly. By close attention to details and to the thermometer, the range of temperature during any one run was kept within one or two degrees. Several different temperatures were tried, from about 2° to 25° C. (35° to 77° F.). The lowest temperatures were obtained by setting the respiration chamber inside a small tank which could be packed with snow. Temperatures around 10° C. were obtained at times by surround-

---

[1] The authors' attention has been called by Dr. Stevens to a little-known paper by Winton (Conn. Agr. Expt. Sta. Ann. Rept. 1902, p. 288), in which is noted the absence of stomata in the epidermis of the cranberry. Bergman, while studying the cranberry, rediscovered this fact, and a paper by him is in press in the bulletin of the Torrey Botanical Club.

[2] Morse, Jour. Am. Chem. Soc. 30 (1908), pp. 876–881; N. H. Agr. Expt. Sta. Bul. No. 135 (1908). Gore, U. S. Dept. Agr., Bur. of Chem. Bul. No. 142 (1911). Hill, Cornell Univ. Expt. Sta. Bul. No. 330 (1913).

ing the chamber with running water, and at others by carrying on the runs in a cool basement. A warm room, such as the laboratory, served for the higher temperatures.

The results given in the following table are selected from a large number of trials, and are those in which the fruit, before and during the experiment, underwent a narrow range of temperature.

TABLE V. — *Exhalation of Carbon Dioxide by One Kilogram of Cranberries in One Hour.*

SURROUNDINGS.	Temperature (Degrees C.).	Determinations.	Milligrams CO_2.
Packed snow,	1–3	5	3.7
Cold room,	6–7	3	7.0
Running water,	9–11	5	7.7
Running water,	11–13	6	9.7
Warm room,	17–20	4	15.4
Warm room,	19–21	3	16.9
Warm room,	22–25	2	18.7

It will be readily seen that the amount of carbon dioxide exhaled doubled with a rise of 10° C. in temperature, which is in accord with the general law for the acceleration of chemical activity.

The temperatures of practical importance are those of cold storage, cool storehouses and warm rooms, or temperatures of 1° to 3°, 9° to 11°, and 20° to 25° C. Cranberries in a warm room are respiring from four to five times as fast as fruit in cold storage, while the fruit in a cool storehouse is twice as active as in cold storage.

These respiration experiments serve to confirm and explain the disappearance of sugar in the cranberries during storage and the increase in such loss at higher temperatures. The rate of respiration helps to explain the asphyxiation of the cranberry described by Shear and Stevens.

By packing cranberries in glass jars and then measuring the amount of water required to fill the air spaces remaining, it was found that in tightly packed barrels of the fruit there could not be more than 75 cubic inches of air for each quart of berries. Since only one-fifth of the air consists of oxygen, it was calculated that in about thirty-six hours, at the cool temperature of 10° C. (50° F.), the cranberries would exhaust the oxygen and replace it with exhaled carbon dioxide. Therefore, if there were no exchange of air between the outside and the inside of a barrel of cranberries, it would be only a few hours before asphyxiation would begin. Fruit, however, does not die as quickly as animals in the absence of air. There is a form of respiration called intracellular respiration, by which sugars decompose to alcohol and carbon dioxide. This is always the result with

yeast in alcoholic fermentation. Similar results are found with fruits. Carbon dioxide has been found to be exhaled by fruit in nitrogen gas[1] at about the same rate as by fruit in air. The destruction of sugar under such conditions is theoretically twelve times as great as when oxygen is available.[2]

In our work with cranberries the rate of destruction of sugar in tight packages was shown to be much greater than in well-ventilated ones. At the same time, it was noted that many berries were very resistant to the conditions, and showed little or no signs of asphyxiation. It is possible that such berries have a lower rate of chemical activity, because, as Gore[3] has shown, the varieties of fruit which may be kept a long time, like oranges and lemons, have a much lower rate of respiration than fruits like grapes and strawberries, which spoil quickly.

A third study of the rate of respiration was made in January and February, 1920, with the object of learning whether the different varieties varied in their activity at a given temperature. It was necessary to have as constant a temperature as could be maintained with the means at our disposal. Through the co-operation of the Pomology Department we were enabled to carry on the work in one of the cold-storage rooms in which the temperature changes were comparatively small and slow, and the different varieties were studied under closely comparable conditions.

The cranberries were received from the Experiment Station bog in November, 1919, and had been held in a room with apples at a temperature of 32° to 33° F., until the respiration experiment was reached in January. They were then transferred to the room in which the respiration apparatus was set up, so that they would be at the temperature of the trial at all times. Four varieties of cranberries were used. The Howes variety was studied, with especial attention to possible changes in the rate of respiration as the storage period advanced, and the other varieties were compared with the Howes and with each other, as there was opportunity. A fresh lot of berries was taken from the crate and carefully hand-sorted for each day's trial in order to exclude any unsound fruit. The experiment was conducted as in all the previous cases.

---

[1] Hill, Cornell Univ. Agr. Expt. Sta. Bul. No. 330.
[2] Palladin, Plant Physiology, tr. by Livingston, Blakiston, 1918, p. 180.
[3] Gore, U. S. Dept. of Agr., Bur. of Chem. Bul. No. 142.

TABLE VI. — *Exhalation of Carbon Dioxide by Varieties of Cranberries.*

Date of Experiment.	Temperature of Berries (Degree C.)	Milligrams CO_2 per Kilo and Hour.			
		Early Black.	McFarlin.	Centennial.	Howes.
January 19,	1.2	3.9	-	-	-
January 20,	.6	-	4.8	-	-
January 21,	.4	-	-	5.6	-
January 22,	1.9	-	-	-	4.8
January 27,	2.1	2.6	-	-	-
January 28,	1.7	-	4.9	-	-
January 29,	2.0	-	-	4.7	-
January 30,	1.7	-	-	-	4.2
February 3,	1.5	3.7	-	-	-
February 4,	2.3	-	4.9	-	-
February 5,	1.8	-	-	5.0	-
February 6,	3.0	-	-	-	4.7
February 11,	3.4	-	5.8	-	-
February 12,	3.2	-	-	5.7	-
February 13,	3.0	-	-	-	4.9
February 16,	3.0	-	5.0	-	-
February 17,	2.3	-	-	-	4.2
February 25,	3.9	-	-	-	4.3
February 26,	3.6	-	-	4.7	-

The table shows a pronounced difference between the Early Black and the Centennial in the rate of respiration, but very little, if any, between the Howes, McFarlin and Centennial. There is a slight indication of a decrease in activity by the Howes as the storage period lengthened. Theoretically this decrease should occur, but on account of other variables it is not readily demonstrated. Since Early Black had passed its prime for quality at the date of the experiment, it is possible that its lower activity was due to a loss of vitality.

Keeping Qualities of Cranberries in Cold Storage.

Some simple tests of the keeping qualities of cranberries in cold storage have been made in connection with the chemical studies, since it was necessary to have a considerable quantity of fruit on hand to insure plenty of sound berries throughout the season. When the cranberries were re-

ceived from the substation at East Wareham, they were placed in the cold-storage house at the College under the same conditions that were maintained for apples. The cold-storage house is a modern building in which the temperature can be kept practically constant week in and week out, which for apples is just above the freezing point, or between 32° and 33° F. The cranberries were stored in ventilated crates holding a half barrel each. There was some evidence that the berries in the center of a crate decayed a little more than those near the surface, but these crates are as small as will be economical for storage and transportation.

When a sample of fruit was required for the chemical studies, a quantity of berries was removed from a crate, carefully sorted by hand, and the different portions weighed. Especial care was taken to have only perfect fruit for the chemical experiments; therefore some berries were rejected which would have been included among sound fruit by the ordinary methods of sorting for the trade. The shrinkage was consequently somewhat greater than would occur in practical storage. The relative keeping qualities of the different varieties should hold, however.

In the fall of 1918 the cranberries were received at the Experiment Station on September 26, kept in a cool room until October 3, and then placed in cold storage with apples. The first lots were removed on November 20, and others at intervals until February 18. The percentages of perfect fruit are given in Table VII.

For the season of 1919 the cranberries were received in November and placed at once in the storage room with apples. Previously they had lain in the store room at the bog in East Wareham at natural temperatures. The first lot was taken from cold storage on Jan. 13, 1920, at which time the crates were removed to a room without ice for the subsequent respiration experiments, but at no time was the temperature observed to go above 37° or 38° F. in this room, which was insulated from outside temperature changes. In this series of tests one variety was used at a time, but all were examined within a week, so in the table below the dates are given for weeks instead of definite days in which berries were sorted.

TABLE VII. — *Keeping Quality of Cranberries. (Per Cent Sound Fruit.)*

DATE.	Early Black.	Centennial.	McFarlin.	Howes.
1918-19.				
November 20,	-	86.5	74.5	-
December 16,	38.3	-	-	-
January 14,	-	68.0	55.0	78.5
February 18,	-	-	-	75.0
1919-20.				
January 13-20,	46.3	60.6	63.7	64.9
January 27-February 4,	42.5	51.8	53.2	58.5
February 12-17,	-	44.9	52.0	62.1

It is evident from the results that Howes was the only variety that would keep well enough to make storage possible until midwinter in order to extend the marketing season. The other varieties, however, are better in eating qualities, and might be used for the manufacture of jam and jelly in seasons of abundant crops.

Cranberry Vinegar.

In September, 1918, an early frost injured many acres of cranberries, and the question was asked of the Experiment Station whether it was possible to utilize the frosted fruit as a source of vinegar. Consequently a lot of the frozen berries was secured by Dr. Franklin for the preparation of some juice for a fermentation experiment. It was found impossible with a machine to separate rotten berries from the fruit softened by the frost, and the cranberries were used without sorting.

The juice was pressed from the berries early in October by means of a hand cider mill. A lot of juice from sound fruit was prepared at the same date for comparison with regard to quality. Both lots of juice possessed a very disagreeable, bitter, acid taste. They remained under favorable conditions for fermentation until December 19, when they were received at the chemical laboratory for analysis.

Careful tests were made for alcohol in the juice by repeated distillation to concentrate it, and the application of the iodoform reaction to the final distillates. Neither juice showed more than a trace of alcohol in the final reaction, so that little fermentation had occurred.

Total acid and total sugar were determined in the different juices by the methods employed for the cranberry analyses. The results were found to be 2.3 per cent acid and .8 per cent of sugar in the juice from frozen berries, and 2.9 per cent acid and 2.6 per cent sugar in the juice from sound berries. Had the sugar all fermented to acid there would not have been sufficient strength to make a legal vinegar, while the taste would condemn its use in any case. Freezing resulted in a marked lowering of sugar in the fruit. The failure to ferment freely is probably due to the benzoic acid, which is a natural constituent of the cranberry. It does not appear practicable to utilize waste cranberries for vinegar.

Summary.

This bulletin reports the results of a chemical investigation made on the changes taking place in stored cranberries.

After the cranberries are picked from the vines they still remain living organisms. Storage conditions should be such that the life of these organisms may be prolonged instead of death being hastened.

Cranberries lose some of their sugar during storage. This loss is due to the respiration of the living berries, which respiration is less rapid at low temperatures than at high temperatures. For this reason the warmer the berries are kept the greater the loss of sugar during storage.

In order to have complete respiration, berries require a constant supply of oxygen during storage. Without this they become asphyxiated and die prematurely.

Good storage must include control of both ventilation and temperature.

Methods.

For the Determination of Chemical Composition.

In drying the cranberries for the determination of water it was necessary either to puncture the skin of the berry in numerous places with a pin, or to cut it into quarters with a knife. Fifty grams of cranberries were punctured or cut in pieces and spread in a shallow glass dish which was placed in a drying oven at a temperature between 50° and 60° C., where it remained until the fruit was brittle enough to be easily pulverized. The dish and contents were then cooled in the open air and the weight of dried material ascertained, after which it was pulverized and stored in a tightly corked bottle. Weighed charges of the air-dry material were subsequently used for moisture determinations, and the total water content of the cranberries calculated.

For the determination of sugar and acid, 50 grams of cranberries were mashed, a few at a time, in a porcelain mortar and washed with water into a 500 cubic centimeter volumetric flask by the aid of a wash bottle, short-stemmed funnel and long glass rod. The flask and contents, which amounted to 300 cubic centimeters, were set on a boiling water bath and allowed to stand about one hour. The flask was frequently shaken, and the pulp and water finally made a fairly homogeneous mass through which the sugar and acid were diffused. The liquid was cooled to room temperature and made up to 500 cubic centimeters. The flask was shaken and the contents then poured on a fluted filter large enough to hold the whole. The funnel was covered and a flask used to catch the filtrate so that evaporation would be reduced as much as possible. Aliquots of 100 cubic centimeters were used for sugar determinations, which were limited to the total sugar after inversion. Clarification was accomplished with Horne's dry lead subacetate, and the soluble lead in the cleared solution was removed by dry sodium carbonate.

Total acidity was determined in aliquots of 25 cubic centimeters of the cranberry solution, which were diluted with several volumes of water and titrated with tenth-normal sodium hydrate, using phenolphthalein as the indicator. The pink color of the cranberry solution seemed at first to make the use of an indicator almost impracticable, but the cranberry pigment proved to be a crude indicator itself. As the alkali was added the pigment changed from pink to blue, and subsequently faded to a pale green as more alkali was introduced. The end point was clearly marked by the appearance of a dark purple tint when the turning point of phenolphthalein was reached. The total acid was calculated as citric acid, though benzoic acid[1] and malic acid[2] have been shown to occur in small quantities in the cranberry.

The proximate food constituents — ash, protein, fiber, ether extract and nitrogen-free matter — were determined in the dried material by the standard methods.

Ether extract from the cranberry is a mixture of true fat from the seeds, wax from the skin and more or less of the fruit acids, — citric, malic and benzoic, — all of which are soluble in ether, the last most easily. In some of the samples the ether extract was warmed with the addition of water, and its acidity determined, but as it could be only an approximate correction it was thought best to leave the total ether extract uncorrected for acids present in it.

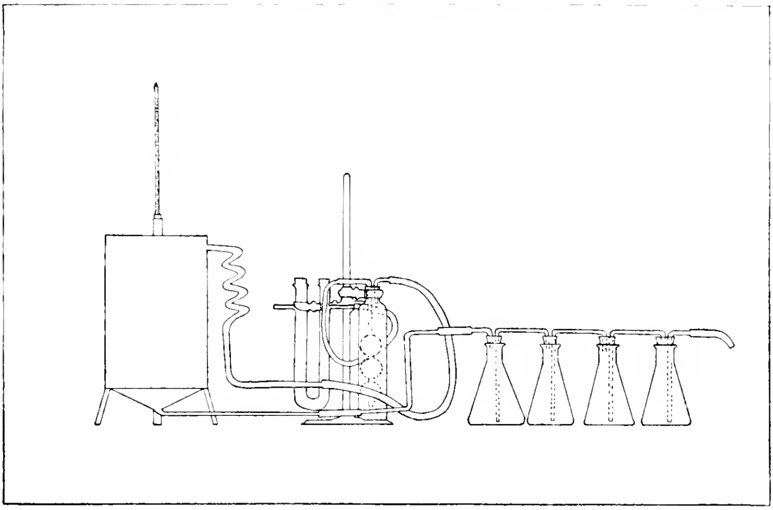
---

[1] Mason, Jour. Am. Chem. Soc. 27 (1905), p. 613.

[2] Bigelow and Dunbar, Jour. Indus. and Engin. Chem. 9 (1917), p. 762.

For the Determination of Rate of Respiration.

The apparatus consisted of a respiration chamber into which air freed from any carbon dioxide could be drawn, and from which the air could be conducted through a liquid which would absorb all of the exhaled carbon dioxide carried along in the current.



Respiration Apparatus.

The respiration chamber was of tin and would hold about 3 quarts. It was open at the top and was closed by a disk of tin which rested on a narrow shelf extending around the inner wall a half inch below the top. The bottom was funnel-shaped with the outlet for the exhaled gas projecting from the lowest part, so that the carbon dioxide, which is heavier than air, could be completely removed. The inlet for purified air was just below the cover of the chamber. Inside the chamber was a loose, false bottom, perforated with numerous small holes, which prevented the cranberries from settling down and blocking the outlet. The false bottom supported a tube three-eighths of an inch in diameter which rose through the center of the chamber and projected an inch above the cover. This tube was also perforated with holes in the portion below the cover, and served to hold a thermometer and to permit free circulation of air through the mass of berries. The cover was sealed in place by means of putty around the inner walls and the central tube, and a cork, through which passed the thermometer, stopped the tube. The outer end of the inlet tube was joined to the purification apparatus which consisted of a U tube containing dry soda lime, and a bulb tube containing a strong solution of sodium hydroxide. The air bubbling through the solution was moistened before entering the chamber, while the bubbles marked the movement of the air and served to indicate leaking joints. The outlet tube connected with a train of four small flasks, each of which contained a measured amount of standard solution of barium hydroxide, by which all the carbon dioxide was absorbed and precipitated as barium carbonate. A current of air was drawn through the entire apparatus by an aspirator which was regulated so that the air in the respiration chamber would be renewed about once in every hour. As a rule, each experiment was run six hours. Some were conducted for longer periods, but six hours was most convenient and satisfactory.

FUNGI STUDIES.

BY BERT A. RUDOLPH AND H. J. FRANKLIN.

Relative Prevalence of Fungi causing Rots of Cranberries at Different Periods during the Storage Season.[1]

Decay of cranberries in storage has been reported to be caused by more than ten species of fungi. The study of these storage rots and their control is complicated by the fact that the fungi causing them vary greatly in their relative abundance during different seasons. Moreover, berries from the various bogs within a given region are often found to be affected with different fungi, and there is apparently some difference in varieties on the same bog. Finally, in any given lot of berries there seems to be a more or less definite succession among the fungi causing decay during the storage period. The present paper deals especially with the last-mentioned point.

The plan of work in 1916–17 was as follows. Twelve storage boxes (1 bushel capacity) were filled with Early Black cranberries from a uniform area on the station bog at East Wareham, Mass., and placed in storage in the basement of the screen house, together with a similar lot of Howes. Beginning September 27 quart samples of sound berries were selected weekly from each variety and stored for two weeks in quart cans (which were closed but not sealed) at room temperature, after which they were sorted, and the berries which had rotted during the two weeks were sent to Washington. Here at least 60 cultures were made[2] from each lot of rotten berries by sterilizing the outside of the berry by immersing for five minutes in mercuric chloride solution (1–1000) and transferring a portion of the pulp to culture media by means of sterile forceps. In case fungi developed which did not fruit readily on the culture medium first used, subcultures were made on oat, beef, glycerine and corn-meal agar.

In the work of the season of 1917–18 the method was modified in several particulars. Closed cans were abandoned in favor of open boxes for the storage of the selected sound berries, the interval between tests was four

[1] The work summarized in this paper forms a part of the study of the spoilage of cranberries after harvest, which is being carried on jointly by the Massachusetts Agricultural Experiment Station and the United States Department of Agriculture. For further information on this general subject see Mass. Agr. Exp. Sta. Buls. Nos. 168 and 180, and U. S. Dept. Agr. Bul. No. 714.

[2] The fungi were all cultured and identified by Rudolph, whose enlistment in the navy late in 1917 prevented the completion of the work planned for that season. Mr. Rudolph was at that time scientific assistant, fruit disease investigations, Bureau of Plant Industry.

weeks, and the sound berries selected for each keeping test were divided into two lots, one of which was kept at room temperature and the other at a constant temperature of 20° C. The only considerable difference in the results due to the difference in method is that the number of sterile (*i.e.*, apparently smothered) berries was smaller during the season of 1917–18. In this respect the results of the second year are more reliable. Storing the berries at a constant temperature (20° C.) apparently changed the results little, which indicates that, in so far as concerns the kinds and abundance of the fungi which developed, those obtained in 1916 with the berries stored at room temperature are satisfactory.

More than a dozen species of fungi occurred in the cultures made during the first season. Of these, seven are known to be more or less important causes of decay of cranberries in storage, namely, *Guignardia vaccinii* Shear (early rot); *Glomerella cingulata vaccinii* Shear (bitter rot); *Fusicoccum putrefaciens* Shear (end rot); *Ceuthospora lunata* Shear (black rot); *Sporonema oxycocci* Shear (ripe rot); *Penicillium* spp. (soft rot); and *Phomopsis* sp. Table I shows the relative prevalence of the four most abundant of these fungi in terms of the percentage of the total number of spoiled berries. Occasionally the percentages recorded total more than 100, an apparent discrepancy which is accounted for by the fact that two or more fungi frequently develop from a single berry.

TABLE I. — *Most Important Fungi causing Storage Rot of Cranberries at Massachusetts State Experiment Bog, East Wareham, 1916.*

[Figures indicate per cent of total spoiled berries infected with each fungus.]

Storage Period.	Glomerella.		Phomopsis.		Sporonema.		Fusicoccum.		Sterile.	
	Blacks.	Howes.	Blacks.	Howes.	Blacks.	Howes.	Blacks.	Howes.	Blacks.	Howes.
Sept. 27–Oct. 11,	3	-	63	-	3	-	20	-	13	-
Oct. 14–18,	30	30	37	40	3	0	7	3	17	23
Oct. 11–25,	7	47	40	20	3	3	7	17	40	17
Oct. 18–Nov. 1,	15	47	36	7	15	0	33	30	0	13
Oct. 25–Nov. 8,	0	13	40	0	3	0	13	53	47	23
Nov. 1–15,	0	6	13	0	3	0	47	60	37	33
Nov. 8–22,	3	20	17	7	0	0	53	47	20	23
Nov. 16–30,	0	27	13	3	0	0	47	50	43	16
Nov. 23–Dec. 7,	0	3	17	3	0	0	40	70	47	20
Nov. 29–Dec. 13,	0	13	13	7	7	0	47	20	50	56
Dec. 6–20,	0	7	7	7	0	0	46	50	37	27
Dec. 13–27,	0	0	10	3	0	0	33	30	57	60

Comparing first the fungi found in the two varieties during this season it will be noted that Sporonema is much more abundant on the Early Blacks, though even on this variety it is not of very great importance. Phomopsis is considerably more common on the Early Blacks and Glomerella on the Howes. Fusicoccum (end rot) is an important storage rot on both varieties. Such differences as have been noted between the varieties may well be accidental. Howes usually bloom three to eight days later than Early Blacks, and thus might be in a condition of susceptibility to certain fungi at different times from the Blacks.

TABLE II. — *Cranberry Blooming Period at the Station Bog, East Wareham, Mass.*

YEAR.	Early Black.	Howes.
1913,	June 20–July 14	July 1–July 18
1914,	June 26–July 20	June 30–July 23
1915,	July 1–July 20	July 9–July 26
1916,	July 1–July 18	July 5–July 22
1917,	July 3–July 23	July 9–July 28
1918,	June 25–July 12	June 28–July 15

Certainly it would be unsafe to assume, without very extensive study, that either variety was especially susceptible to a given fungus.

The relative importance of the various fungi at different times during the storage season is most easily seen from the graphs, Figs. 1 and 2. In both varieties Phomopsis and Glomerella are most abundant early in the storage season, and become gradually less important. Fusicoccum, on the other hand, is relatively scarce early in the season, and becomes very much more abundant as the season advances, so that after the 1st of November end rot is more important than all the other rots combined. That this relation does not always hold is proven by the records of the succeeding year, but it seems probable that, in Massachusetts, end rot is the most serious cause of decay in stored cranberries during the latter part of the season. End rot in early stages can be identified on the fruit with a fair degree of certainty by careful observers, and its importance as a cause of loss in stored fruit has been emphasized by Mr. H. S. Griffith, chairman of the inspectors of the New England Cranberry Sales Company, in his report for 1919 (page 21).

The results of the second year's work as given in Table III show interesting resemblances to those of the previous year.

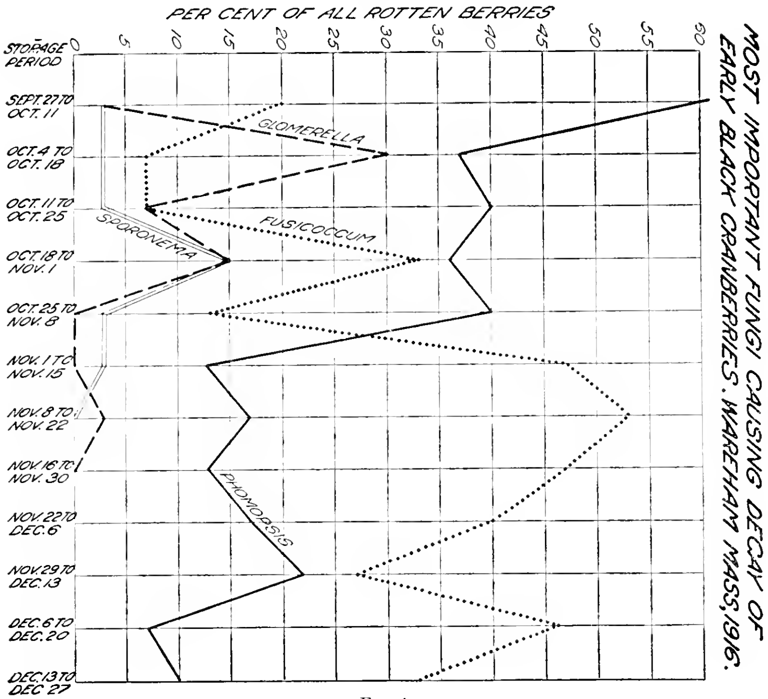

PER CENT OF ALL ROTTEN BERRIES
0
5
10
15
20
25
30
35
40
45
50
55
60
STORAGE PERIOD
SEPT. 27 TO OCT. 11
OCT. 4 TO OCT. 18
OCT. 11 TO OCT. 25
OCT. 18 TO NOV. 1
OCT. 25 TO NOV. 8
NOV. 1 TO NOV. 15
NOV. 8 TO NOV. 22
NOV. 16 TO NOV. 30
NOV. 22 TO DEC. 6
NOV. 29 TO DEC. 13
DEC. 6 TO DEC. 20
DEC. 13 TO DEC. 27
GLOMERELLA
FUSICOCCUM
SPORONEMA
PHOMOPSIS
MOST IMPORTANT FUNGI CAUSING DECAY OF EARLY BLACK CRANBERRIES. WAREHAM MASS, 1916.

FIG. 1.

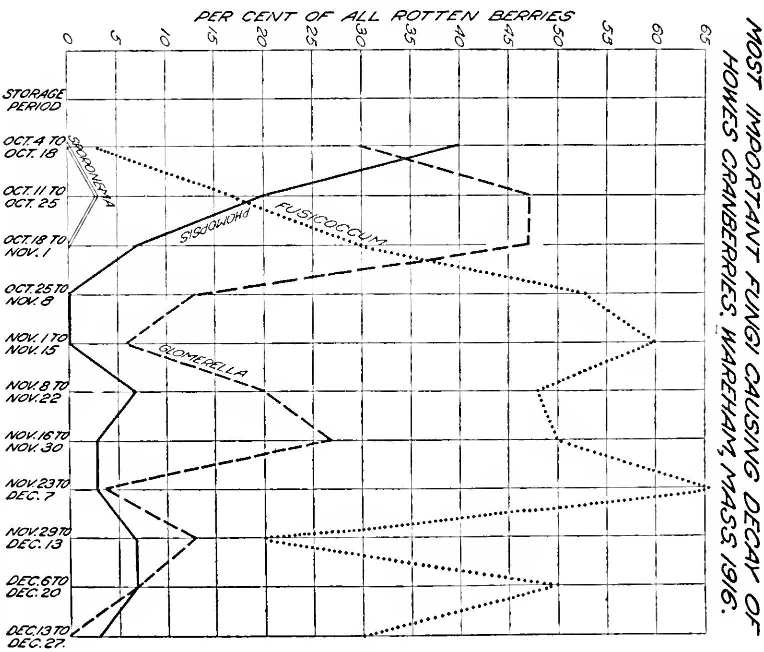

PER CENT OF ALL ROTTEN BERRIES
0
5
10
15
20
25
30
35
40
45
50
55
60
65
STORAGE PERIOD
OCT. 4 TO OCT. 18
OCT. 11 TO OCT. 25
OCT. 18 TO NOV. 1
OCT. 25 TO NOV. 8
NOV. 1 TO NOV. 15
NOV. 8 TO NOV. 22
NOV. 16 TO NOV. 30
NOV. 23 TO DEC. 7
NOV. 29 TO DEC. 13
DEC. 6 TO DEC. 20
DEC. 13 TO DEC. 27.
SPORONEMA
PHOMOPSIS
FUSICOCCUM
GLOMERELLA
MOST IMPORTANT FUNGI CAUSING DECAY OF HOWES CRANBERRIES. WAREHAM, MASS. 1916.

FIG. 2.

TABLE III. — *Most Important Fungi causing Storage Rot of Cranberries at Massachusetts State Experiment Bog, East Wareham, 1917.*

[Figures indicate per cent of total spoiled berries infected with each.]

Storage Period.	Storage Temperature (Degree C.).	Glomerella.		Phomopsis.		Sporonema.		Fusicoccum.		Sterile.	
		Blacks.	Howes.	Blacks.	Howes.	Blacks.	Howes.	Blacks.	Howes.	Blacks.	Howes.
Before storage, . .	–	61	89	5	5	22	4	9	1	11	4
Storage ended Oct. 15,	20	12	76	30	3	15	0	21	3	15	7
	13[1]	23	88	40	4	20	0	13	1	11	8
Storage ended Nov. 12,	20	12	82	32	2	0	0	40	4	20	10
	18[1]	12	51	18	6	8	6	58	12	6	24
Storage ended, . .	20	2	43	10	3	3	3	67	18	9	23
	5[1]	1	31	3	6	2	3	58	36	11	10

[1] Estimated from outside temperature and from temperature of same room during the same periods of the previous year.

As in 1916 Sporonema is the least important of the four, and is found chiefly on the Early Blacks. Phomopsis is again more common on the Early Blacks, and Glomerella on the Howes; indeed, the contrast is more striking in 1917 than in 1916. During both years Phomopsis and Glomerella are more abundant early in the season, while Fusicoccum is rare early in the storage period and becomes more abundant later. The most unusual feature presented by the results is the very great abundance of Glomerella on Howes during 1917, and the relative scarcity of Fusicoccum.

So far as is now known infection by the various fungi causing decay of cranberries generally occurs before the berries are picked. That the development of the fungus is often delayed for some time is evident from the data here published, when it is recalled that in every case only apparently sound fruit was used for the storage test. The conditions necessary for the further development of a fungus already in the fruit or attached to the outer epidermis as a spore or appressorium are not yet determined. That it is not entirely a matter of condition of the berry is apparent from the fact that end rot, for example, becomes abundant on the Howes as soon as on the riper Early Blacks; and that it is not a matter of temperature appears (see Table III) from the fact that berries kept at 20° C. showed no marked difference in this respect from berries kept at lower temperatures.

BULLETIN No. 199.

DEPARTMENT OF POULTRY HUSBANDRY.

BROODINESS IN DOMESTIC FOWL.

DATA CONCERNING ITS INHERITANCE IN THE RHODE ISLAND RED BREED.

BY H. D. GOODALE, RUBY SANBORN AND DONALD WHITE.

INTRODUCTION.

Broodiness, as pointed out by Herrick (1907a, 1907b), is one phase of a recurring cyclical process in birds. In the domestic fowl when kept primarily for egg production, the instinct is not allowed to run its normal course, but is checked by suitable means in its initial objective stages. Some individuals, however, never exhibit the instinct. In this study of the inheritance of broodiness two categories of birds may be recognized, viz., those that exhibit the initial stages of broodiness, which are promptly checked, and those that do not exhibit any signs of broodiness. Broodiness is intimately connected with egg production, and, other factors being equal, its presence or absence determines the number of eggs laid, since, as shown later, its presence tends towards decreased production. A knowledge of its inheritance should show the steps necessary for its complete elimination from a flock.

The character, moreover, is not a superficial and unimportant one, but is a well-defined characteristic of the class Aves, and is essential for the survival of every species in the class. If the instinct were lost in a state of nature, without being replaced by some compensating mechanism,[1] the race would become extinct. In nature selection is constantly directed in favor of the character, since those individuals that lack it will leave no progeny, yet among domestic fowl we find entire races in which the character is lacking.

Poultrymen recognize both broody and non-broody races. The American breeds, *i.e.*, Plymouth Rocks, Rhode Island Reds and Wyandottes, and

[1] It is well known, of course, that the American cowbird and the European cuckoo have developed a compensating mechanism.

the Asiatics, *i.e.*, Langshans, Cochins and Brahmas, may be cited as examples of the former, while Hamburgs and Campines, and the Mediterranean breeds, *i.e.*, Leghorns, Spanish and Anconas, furnish examples of the latter. The distinction is based on the proportion between broody and non-broody individuals in each race, for some non-broody individuals occur among the broody races, while records are lacking to show that broody individuals are entirely absent from any of the non-broody races. The Leghorns are commonly regarded as a non-broody race, but as shown in Table VI, taken from the report of the fifth laying contest at Storrs (Kirkpatrick and Card, 1917), a considerable number become broody. It is a matter of common knowledge among poultry keepers that among the broody races there are considerable differences, some races, of which the Rhode Island Reds are an example, having an intense development of broodiness compared with others, such as the Barred Plymouth Rocks, in which the amount of broodiness is relatively slight.

There are few published reports on the character in the domestic fowl, though there is, of course, a considerable amount of matter scattered through the poultry literature, in which broodiness is mentioned in a more or less general way, but which is of no importance from the standpoint of this paper. Both Bateson's (1902) and Hurst's (1905) data showed that in a cross between a broody and non-broody race, broodiness was dominant, but they have published no further observations. Pearl (1914) has published certain data relating to broodiness, with which in general our data agree. A repetition of the same sort of material is unnecessary here. His methods of collecting the data and of handling the broody birds also are essentially the same as our practices in these respects. In general, our experience with this instinct agrees with his, except that there are two points for which different interpretations may be presented. On page 285 (*loc. cit.*) he makes this statement: "It appears to be the case that in the domestic fowl the brooding instinct has to a very large degree disappeared along with the fact of domestication." Evidently this author had not encountered a strain like our Rhode Island Reds, for such a statement would be impossible after an experience with such a strain. In the second place, we entertain some doubt as to the advisability of measuring the intensity of broodiness by the length of the non-productive period associated with the objective symptoms of broodiness (*loc. cit.*, page 273), because, while the cessation of egg production coincides in nearly every instance with the onset of objective symptoms, the resumption of production is often delayed by other factors, among which may be noted the innate capacity for egg production and readiness to molt. In regard to its effect on egg production, Goodale (1918) makes the statement that the ratio between the egg production prior to the first broody period and that subsequent thereto is about 100:60.[1] Gerhartz (1914) has studied the metabolism of the broody hen in connection with his studies on the metabolism of the laying hen.

[1] The data on which this statement is based are given for the first time in Table VIII.

The Material and its Treatment.

The materials for the present study of the inheritance of broodiness are the pullet-year trap-nest records of the flock of Rhode Island Reds, bred at this station from 1913 to 1917, primarily to furnish data on the inheritance of fecundity. The usefulness of these data is limited in one important respect, since, as discussed in the section on variation, a year's record is not long enough to determine a hen's capacity for becoming broody. Limitations in housing capacity and labor have hitherto prevented the retention of non-broodies as long as was desirable. In the handling of the data, therefore, we have classified birds as broody or non-broody on the basis of the pullet-year records only, even though on this basis the non-broody class will contain more birds than it should. However, the theories of the inheritance of broodiness to which we have been led could not be substantiated from the available data, even if the difficulty under discussion were removed.

Recognition and Treatment of Broody Birds.

The recognition of a broody period is an easy matter with slight experience. The onset of broodiness is usually sudden. On the last visit to the trap nests late in the afternoon one or more birds are found that are very much disinclined to leave the nest. If they cluck and ruffle their feathers the diagnosis is certain, and the birds are removed to the broody coop to be "broken up." Sometimes part of the symptoms are lacking. In case of doubt the bird is merely removed from the nest. By the following afternoon, if she is really broody, all symptoms are well manifest. Mistakes are not easily made.

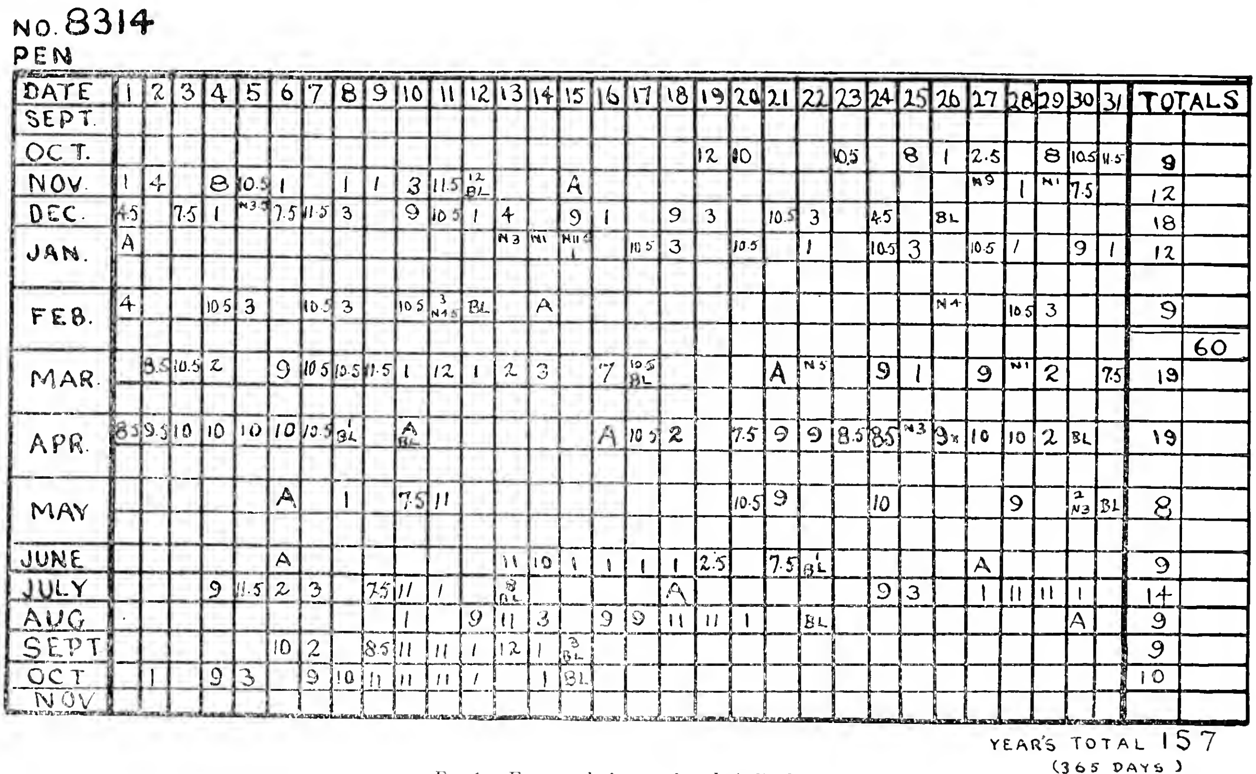
The broody coop in which the broody hens are confined, in order to prevent the instinct from running its normal course, is a box with slatted sides, top and bottom. The routine practice in dealing with broodies is to place all the broodies found in each pen in one of these coops. The same coop also receives the broodies on each of the two days following. Three days later the entire lot is released as a unit. Thus, the birds are confine l from three to six days each, a period which is sufficient for the majority to "recover from the attack." A few, however, require a longer period of confinement. The confined broody individuals are supplied *ad libitum* with the same sort of food and water supplied the rest of the flock.

A bird must, as a rule, be classified either as broody or not broody, though in a few rare instances birds have exhibited a part of the broody symptoms only, as, for example, when a hen clucks and ruffles her feathers, but does not remain on the nest continuously, nor cease laying.

Variation in Amount of Broodiness.

A bird once broody may exhibit the character in various degrees which can be classified under two heads, — first, variation in the number of times a bird becomes broody in a period of given duration, usually the laying year; and second, variation in length and intensity of the individual broody periods. The latter is the less important of the two, for the length of time required by the vast majority of birds to "recover" from the attack is of comparatively small importance. To be sure, some birds take double the time that others require in "recovering," but it is an extreme case when more than a week is required, if no extraneous factors are present. Further, on forming a correlation table between number of days confined and subsequent egg production, it became evident that the coefficient of correlation (though not calculated) was so small that no relationship of importance existed between the subject and relative. The large factor in variability in broodiness is found in the variation in the number of times the broody cycle is repeated, as is shown later on.

Four sample egg records are shown here to illustrate individual variations in amount of broodiness. A numeral in a square indicates the hour at which an egg was collected; B. L., broody and placed in broody coop; A, released from broody coop; N, associated with a numeral, means that the bird visited the nest, but did not lay.



NO. 8314
PEN

DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	TOTALS	
SEPT.																																	
OCT.																			12	10			10.5		8	1	2.5		8	10.5	11.5	9	
NOV.	1	4		8	10.5	1		1	1	3	11.5	12 BL			A												N9	1	N1	7.5		12	
DEC.	4.5		7.5	1	N3.5	7.5	11.5	3		9	10.5	1	4		9	1		9	3		10.5	3		4.5		BL						18	
JAN.	A												N3	N1	N11.5 1		10.5	3		10.5		1		10.5	3		10.5	1		9	1	12	
FEB.	4			10.5	3		10.5	3		10.5	3 N1.5	BL		A												N4		10.5	3			9	60
MAR.		8.5	10.5	2		9	10.5	10.5	11.5	1	12	1	2	3		7	10.5 BL				A	N5		9	1		9	N1	2		7.5	19	
APR.	8.5	9.5	10	10	10	10	10.5	1 BL		A BL						A	10.5	2		7.5	9	9	8.5	8.5	N3	9x	10	10	2	BL		19	
MAY						A		1		7.5	11									10.5	9			10				9		2 N3	BL	8	
JUNE						A							11	10	1	1	1	1	2.5		7.5	1 BL					A					9	
JULY				9	11.5	2	3		7.5	11	1		8 BL					A						9	3		1	11	11	1		14	
AUG.										1		9	11	3		9	9	11	11	1		BL								A		9	
SEPT.						10	2		8.5	11	11	1	12	1	3 BL																	9	
OCT.		1		9	3		9	10	11	11	11	1		1	BL																	10	
NOV.																																	

YEAR'S TOTAL 157
(365 DAYS)

Fig. 1.—Egg record of a very broody individual.

NO. B3700
PEN

DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	TOTALS	
SEPT.																																	
OCT.																																	
NOV.																					11.5		7	9.5	3		9	2		8		7	
DEC.	N3	N3.5	3		7.5	9.5	2.5		7.5	8	10	11	11.5	3			9	10	1	4			3		8	9.5	11	4		7.5	10	21	
JAN.	11.5	N3.5		7.5	8.5	10	11.5	4.5		8	9.5	10.5	2	3.5		8	11	11.5	1	4		8	9.5	11	10.5	10.5	11	N2.5	N4.5		8	23	
FEB.	11.5	12.5	4		9	10	11	N3		4		10.5	10	11.5	3.5			8.5	10	11.5	3.5		8.5	8.5	10	1	1.5	4.5				21	72
MAR.		8	2		8.5	10	N3	N3.5		8.5	1.5		8.5	10	1.5		8	9.5	12	11.5	11.5	11.5	N2	4 N5.5		8.5	10.5	4		N1	11.5	20	
APR.	3	3	N4	4		9.5	9.5	N2	N6		9.5	11	N2.5			10	11.5	2	12.5	1	2.5	4.5		N1	9.5	11	12	2.5 N5.5	BL			18	
MAY.				A		N11		N8		9.5	N3	N5.5		9	9	9.5	9.5	10.5	10.5	11.5	10	N3	11.5	10	9	2 N5.5	BL					13	
JUNE			A				N2.5	4.5		9.5	11.5	11.5	11.5	12.5	3		9.5	9.5	11	11	11	3 N5.5	BL				A	N4.5				13	
JULY		N9							2		9.5	2.5		11	12	3.5		9	10	9.5	9 N5.5	1.5C BL				A						11	
AUG.									N9	12			9.5	9.5	10.5	N3.5	4.5			1.5		8.5	10	10	10	1.5 NS	N2 BL					11	
SEPT.				A														N9.5	3		10	11	5		NS	3		9.5	9.5	11		8	
OCT	11	11	11	1	12.5	3 NS	BL						A																			6	
NOV.																																	

YEAR'S TOTAL 172
(365 DAYS)

FIG. 2.—Egg record of a bird becoming broody about midseason.

NO. B 3226
PEN

DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	TOTALS	
SEPT.																																	
OCT.																																	
NOV.										N3												N10 N11.5 1.5		8.5	9	3		7.5	8.5	11		7	
DEC.	11	11	1.5	3		8.5	10	9.5	10.5	1.5		8	10	2		8	9	10	11	11	11	2	1	4		N4	8.5		10.5	3		24	
JAN.	8.5	10	1.5	3.5		8	10	11.5	N11 4		9.5	10.5	2	4.5		8	9.5	10	1	4		8	N1	11	3		8	9	9	11	11	25	
FEB.	1	4.5		8	9	10	11	11.5	1.5	2.5	5		N8.5	10	1	3.5		8.5	1	2		8	10.5	3.5		8.5	11.5	3.5				22	
																																	78
MAR.		8	10.5	10.5	1.5	3		8	10.5	11.5	N3		8.5	N3.5			N1	2		7.5	10	11.5	11.5	11.5	12	1.5	1	1.5	5.5		9.5	21	
APR.	12	12	2	2	6		9.5	11.5	2.5	2	5.5		9.5	11.5	12.5	1.5			9.5	11	2.5	4.5		9.5	11	11	12	12	12.5	5		25	
MAY		9.5	N12	12.5	3	3.5	N6		12.5 N6	4.5 N5.5	BL						A N6.5					N8	N6		9	10.5	N3 12	3.5	N4 6		9.5	12	
JUNE	11.5	12	2.5		N0.5	11 L0	12.5	4.5		11.5	3		11	5	N12.5	1	N8.5	12.5	N2.5	N5 N10.5 [illegible]		N8 N11 12.5	N8 N4	N8 N10.5 2	N12 3.5	N5	9.5	N8 N10.5 4.5	N9 N4	N8 10.5		19	
JULY	N12 2.5	N9 N6	9	11.5	3		9	N8 2	N9.5 N12 3.5	N8 N12.5	N8 11	12.5	5		10.5	1.5	5		11	3		11	3.5	N8	8	2	N4.5	9.5	2		9.5	22	
AUG.	1	3.5		9	11.5	5.5	N3	10.5	3		10.5	12	4.5	N3	9.5	2	4.5		11.5		N3.5	N2.5	11.5	4	N1	10	1.5		10.5	3.5	N11.5	20	
SEPT.	11.5	3.5 N5		10.5	3		11	5		11	5	N1	11	4.5		1.5																11	
OCT.					N11																											0	.
NOV.																																	

YEAR'S TOTAL 208
(365 DAYS)

FIG. 3.—Egg record of a bird becoming broody only once the first year, and that at midseason.

NO. B640
PEN

DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	TOTALS	
SEPT																																	
OCT.																											2			1		2	
NOV.	8.5	10	4.5		8	10	4.5		9	1.5	4		7.5	10	3		8	9	10	11	3		8	9	2		7.5	9.5	10			23	
DEC.	9	12				10.5	3		7.5	9	1	3		9	10	11	4		7	9	9.5	11	1	2.5		7	10.5	3.5	7		11	23	
JAN.	1	4		9	11	3		8	10	1.5	4		9	105	4		8.5	11	4		8	11	35		8.5	11	3		8.5	1.5	N3 4	24	
FEB.		10	1	4		11	3		8.5	2	2		8.5	12	4		10	3		8.5	3	4	9		11	4		9.5				20	92
MAR.	10	4		9	9.5	12	5		9.5	11	2		8	10	4		10	10			8.5	5		9	1.5		11	2		9.5	3	22	
APR.	6		12	5		11	5		3		2.5		2		12	1	4			3		12	5		10	6		2		11		18	
MAY		2		4		4		1		10	4			12		10	4	6		11	4		11	2	3	12	5		10.5	2	3	20	
JUNE		1		10	12	3		2		12	3		11		11	12	4		9.5	2		10	3				1	3				17	
JULY		5		3		N3 11	45		1		11		11	4		11	5		11			1		11.5	4		1.5		1		10	17	
AUG.	1		5	11	3		11		10	N10 3		11	3		10	2	5		11	1	5		10	1	5		10	3	N3 5	NSC BL	A	21	
SEPT.	BL		A																													0	
OCT.																																0	
NOV.																							10		10	1		10	1			5	

YEAR'S TOTAL 207
(365 DAYS)

FIG. 4.—Egg record of a bird becoming broody at the end of the laying year.

Figures 1, 2 and 4 are examples of variability in number of broody cycles. It will be observed that there is a period of production of variable length before the first broody period makes its appearance. This may come soon after production begins (Fig. 1), or may be delayed till near the end of the season (Fig. 4), or even till subsequent seasons. After the first broody period subsequent periods occur in fairly regular sequence, the cycle of broody, rest and production being repeated over and over. It is obvious, then, that the number of broody periods occurring during the first year will be determined in part by the time of year the first broody period occurs. After one broody period it becomes a question of the number of additional cycles that are added before a bird stops laying for the season. In the extreme case of Fig. 4, production was not resumed after the first broody period, which came late in the season.

In later years there has been much less regularity in the recurrence of the broody periods in that part of the flock bred specifically for increased egg production, but the parallelism does not necessarily mean that the latter has caused the former. It is noticeable that the broody periods are fewer in number and limited to the height of the broody season in many individuals, which afterward may become regular producers, without further evidence of broodiness in that season. For example, instances are quite common where a single broody period occurs in mid-season, and is followed by continuous production, as shown in Fig. 3. Sometimes there are two or even three such periods followed by continuous production. Occasionally some birds have broody periods occurring at rather irregular intervals.

When birds are kept through the second season it is found that some birds that did not become broody the first season may become broody at some point in the second season. One instance occurred where the bird did not become broody till the third season. Because of the physical limitations in the matter of plant equipment we are unable to give the exact percentage of birds not broody in their pullet year that became broody later on. We have, of course, the data for such birds as were kept over, but we do not believe it gives a fair picture of what will be found in large flocks. They are, however, fairly numerous. There is, moreover, some evidence that various lines behave unlike others in this respect. On the other hand, only four instances free from complications have occurred among our records of birds that were broody the first season but failed to become broody thereafter. It is clear that the pullet year is a good index of the presence of the broody instinct for those birds that actually become broody, but not as good an index for those that do not become broody.

This brief description of variation in amount of broodiness, together with the data given in Table VIII, is sufficient to give the reader a general idea of its nature. Further details are outside the scope of this paper.

Germinal Basis of Broodiness.

The normal or wild condition is the presence of broodiness, otherwise the race could not survive. Hence, any changes from the normal condition of those parts of the germ plasm which are responsible for the existence (as distinguished from amount) of broodiness will probably result in a failure in the appearance of the broody instinct. Broodiness may also, of course, fail to become manifest from non-genetic causes, and hence some genetically broody birds are recorded as non-broody. Non-broodiness, therefore, is a comprehensive term employed to describe the phænotypic condition resulting from several sorts of genetic differences. The situation is parallel, in certain respects, to that of eye color in Drosophila. Red eye is the normal or wild color. Changes in the germ plasm result in a host of other eye colors, which are all non-red. In like manner, from the genetic standpoint, all broody birds are presumably alike in their fundamental broody mechanism, except for the homozygous or heterozygous condition, and, of course, the presence of modifiers discussed in the next paragraph. Non-broody birds, on the other hand, may belong to quite different genotypes. It is, therefore, improbable that any one scheme can be applied to the inheritance of non-broodiness in domestic fowl. Indeed, the data given in Tables II and III indicate clearly that several types of non-broodies exist in the Rhode Island Reds. The presence of these types suggests that still different genetic types of non-broodies will be discovered in other breeds.

It seems clear on general grounds that a distinction must be made between the primary factors concerned with broodiness and modifying factors. The latter may act in various ways on the primary mechanism for the manifestation of broodiness, but they cannot act unless that mechanism is present. We may expect that such modifying factors will control the intensity of broodiness in either a plus or minus direction, and, extending this reasoning to its logical conclusion, such modifying factors may prevent entirely any manifestation of broodiness. Non-broodiness, therefore, may result from some genetic change in the secondary mechanism, as well as in the primary.

There are three possible sorts of matings (the male being treated as though capable of giving phænotypic expression to his genotypic constitution), viz., both parents may be broody, both non-broody, or one broody and the other non-broody. From each of these three possible matings there are three possible groupings of the female offspring, *i.e.*, (1) all may be broody, (2) all non-broody, and (3) part broody, part non-broody, as shown in Table I.

TABLE I. — *Kinds of Offspring expected from all Possible Kinds of Matings.*

Parents.	Offspring.
Both parents broody,	All broody. All non-broody.* Part broody, part non-broody.
Both parents non-broody,	All broody.* All non-broody. Part broody, part non-broody.
One parent broody, the other non-broody,	All broody. All non-broody.* Part broody, part non-broody.

Of the nine possible groupings between parents and offspring, six have been realized in our experience. Those marked with an asterisk (*) have not been realized. Two of the three unrealized possibilities should be realized eventually, and the third, all non-broody offspring from broody parents, is not expected, as is explained beyond.

The preceding table, as well as the ratios in which the offspring occur, Table II, does not agree with the assumption that broodiness is a simple Mendelian dominant and non-broodiness a simple recessive in all instances as Hurst (1905) supposed. If non-broodiness were a simple Mendelian recessive, then the son of a non-broody hen should throw either all non-broodies or half non-broodies when bred to non-broodies, but this does not always happen. Moreover, the establishment of a non-broody strain should have been a much simpler matter than it has proved.

TABLE II. — *A Comparison between Observed and Theoretical Ratios, assuming that Two Factors, A and C, must both be present in order that an Individual may become Broody.*

1915.

Father's Band Number.	Number of Mothers. Non-broody.	Number of Mothers. Broody.	Number of Mothers. Total.	Offspring. Observed Ratio. Non-broody.	Offspring. Observed Ratio. Broody.	Offspring. Expected Ratio. Non-broody.	Offspring. Expected Ratio. Broody.
68,	1	3	4	0	9	0	9
A143,	1	2	3	1	9	0	10
228,	0	3	3	0	5	0	5
269,	3	10	13	7	40	6	41
270,	0	2	2	0	6	0	6
271,	0	4	4	2	15	7/8	16 1/8
272,	0	1	1	0	2	0	2
274,	4	5	9	0	43	0	43
A323,	0	1	1	0	1	0	1
619,	0	2	2	0	3	0	3
2313,	0	5	5	1	30	7/8	30 1/8
2539,	0	1	1	0	1	0	1
2914,	1	2	3	2	7	2 7/8	6 1/8
3003,	4	1	5	11	3	11 3/8	2 5/8
3533,	0	4	4	1	11	7/16	11 9/16
3617,	1	10	11	1	38	1 1/4	37 3/4
4128,	0	4	4	2	10	1 1/2	10 1/2
4167,	3	4	7	5	52	5 1/2	51 1/2
4265,	0	3	3	2	16	2 1/2	15 1/2
Brown,	0	1	1	0	3	0	3
McLean,	0	4	4	1	13	0	14

1916.

Father's Band Number.	Number of Mothers. Non-broody.	Number of Mothers. Broody.	Number of Mothers. Total.	Offspring. Observed Ratio. Non-broody.	Offspring. Observed Ratio. Broody.	Offspring. Expected Ratio. Non-broody.	Offspring. Expected Ratio. Broody.
274	0	2	2	0	8	0	8
3617	0	5	5	6	24	3 1/2	26 1/2
4312	0	1	1	0	8	0	8
4354	1	4	5	5	32	2	35
4378	0	4	4	6	22	5 1/2	22 1/2
4723	0	6	6	15	59	16 7/8	57 1/8
4786	0	2	2	2	6	7/8	7 1/8
4882	0	1	1	5	20	6 1/4	18 3/4
5077	0	3	3	2	10	2 1/4	9 3/4
5240	0	1	1	0	7	0	7
5470	0	1	1	1	2	1 1/2	1 1/2
5477	0	2	2	0	15	0	15
5581	0	7	7	2	42	1 1/2	42 1/2
5584	0	4	4	3	35	0	38
5642	1	0	1	0	2	0	2
5776	0	1	1	0	8	0	8
6265	0	3	3	1	19	0	20
6373	0	4	4	0	22	0	22
6781	1	3	4	14	24	16 3/8	21 5/8
–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–

1917.

Father's Band Number.	Number of Mothers. Non-broody.	Number of Mothers. Broody.	Number of Mothers. Total.	Offspring. Observed Ratio. Non-broody.	Offspring. Observed Ratio. Broody.	Offspring. Expected Ratio. Non-broody.	Offspring. Expected Ratio. Broody.
3003	4	1	5	23	1	22 1/8	1 7/8
5470	4	0	4	13	5	13	5
5581	0	1	1	0	4	0	4
7727	0	2	2	1	3	3/4	3 1/4
7745	0	3	3	4	10	2 1/2	11 1/2
7931	0	1	1	2	1	1 5/16	1 11/16
8027	2	6	8	30	39	27 1/2	41 1/2
8095	1	3	4	3	4	2 13/16	4 3/16
8097	0	5	5	21	22	17 1/4	25 3/4
8147	2	5	7	15	33	18	30
8217	0	3	3	0	9	0	9
8422	1	2	3	7	4	6 1/2	4 1/2
8528	1	5	6	27	32	28 1/4	30 3/4
8761	0	4	4	9	15	7 5/16	16 11/16
9305	0	2	2	2	5	1 1/2	5 1/2
9752	6	5	11	57	16	48 3/8	24 5/8
–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–

Several factorial explanations of the observed ratios between broodies and non-broodies in the several families can be developed, but choice among such explanations cannot be made because of the small size of the individual families, *i.e.*, the offspring of a single mother. Nor are any of them of value save as working hypotheses. The one on which Table II is based is presented simply to show that a close agreement between theory and fact is possible, and this theory was chosen for presentation because it gives a slightly better agreement between observed and theoretical rations, with one partial exception, than the others. This theory assumes that the appearance of broodiness in Rhode Island Reds requires the simultaneous presence of two factors, designated A and C, in either homozygous or heterozygous condition. A better fit in the case of the partial exception can be secured by assuming that there is also a dominant factor (presumably a modifier) for non-broodiness, which may be designated as N. Non-broodies, therefore, may be of numerous genetic types, the homozygous forms being NNAACC, nnAAcc, nnaaCC; and nnaacc, where A and C, respectively, represent the factors (condition of germ plasm) necessary for broodiness. A broody bird, then, in homozygous form must be nnAACC. As shown by Table III, which gives the theoretical ratios expected on both the NNAACC and AACC theories, it will be seen that matings between birds of the same phænotype may give several different ratios, including those in which the proportions between broody and non-broody birds are reversed. Thus (NNAACC theory) broody x broody may give 3 broody to 1 non-broody, or it may give 1

TABLE III. — *The Theoretical Ratios resulting from Matings of Different Types, arranged by Ratios.*

[A ratio appears only once under its respective theory.]

Parents.	NNAACC Theory.		AACC Theory.	
	Progeny.		Progeny.	
	Non-broody.	Broody.	Non-broody.	Broody.
Broody × broody,	7	9	7	9
Non-broody × non-broody,	55 29 15 64	9 3 1 0	16	0
Broody × non-broody,	23	9	5	3
Broody × broody, broody × non-broody,	0 1	64 3	1	3
Broody × non-broody, non-broody × non-broody.	1 13 7	1 3 1	1 3	1 1
Broody × broody, broody × non-broody, non-broody × non-broody.	5 3	3 1	0	16

broody to 3 non-broody, exactly reversing the ratio, as has occurred in the detailed data from which Table II was compiled. It should be stated that while families showing the extreme ratio of 15 non-broody to 1 broody have not been encountered, several instances of the 7:1 ratio have been observed.

The only evidence at present available in support of either of these schemes is furnished by the ratios between the broody and non-broody members of the several families (Table II). N, if it represents a real condition of the germ plasm, occurs relatively infrequently in the flock at present. Practically all the observed ratios, except the partial exception mentioned, can be accounted for if N is omitted.

It is also possible to modify the AACC theory, by assuming that A is sex linked, though no evidence of sex linkage other than an agreement between the observed and theoretical ratios has been noted. Doubtless other schemes could be devised that would also account for the ratios.

Although the ratios themselves could perhaps be explained as chance deviations from monohybrid ratios (though this is doubtful in some instances), or as the result of errors of classification of individuals through failure to manifest the genotypic condition phænotypically, the moment lines of descent are established it becomes clear that a monohybrid explanation does not fit the facts. The data have been worked over in an attempt to apply the monohybrid scheme, *i.e.*, broodiness due to a single dominant factor, but without success. See, for example, the history of male No. 3003 and his offspring, page 107.

In order to establish the existence of any of the schemes under discussion certain results of critical importance must be obtained. Thus, the discovery of a family consisting of all non-broody offspring from the mating between a non-broody and a broody is required to demonstrate the presence of a dominant factor for non-broodiness, while a mating between two non-broody birds that gives all broodies is required as proof of the AACC theory (or a theory of the same order). The ratios at hand indicate the possibility that several genetic types of non-broodies coexist in our strain. One possibility only seems to be excluded if the schemes outlined represent the facts, for one need never expect to find a pair of broody birds that produces all non-broody offspring, because such a result would mean two distinct types of broodies which mutually inhibit each other.

Modifying Factors for Broodiness.

The possibility that the non-broodies dealt with in these experiments are not due to changes in the primary genes concerned with broodiness, but are due to changes in modifying genes, cannot be excluded. As we have worked over the records, the impression has been strong that we are not dealing with a real absence of broodiness so much as with delay in the appearance of broodiness. Unfortunately the present data are inadequate to settle this point. Nor is it likely that we shall have suitable data in the near future, because the somatic manifestations of broodiness,

i.e., the number of times a bird becomes broody as well as the ease with which she is broken up, vary considerably, as already described. Since the chief reason for this variability is found in the number of times a bird becomes broody, which in turn is so thoroughly interwoven with egg production, the same practical difficulties, *i.e.*, disease control, that at present prevent a complete analysis of the inheritance of fecundity also prevent the determination of the hereditary factors involved in degree of broodiness.

The Production of a Strain of Low Degree of Broodiness through Selection.

Two lines of selection have been under way, — one for the elimination of broodiness, the other for its development to a high degree, equal to or greater than that observed in the case of Fig. 1. Because most of our facilities were needed in other directions, little has been done with the plus line beyond its maintenance. The minus line, however, has been closely involved with the problem of securing increased egg production, since absence of broodiness tends toward higher production, other things being equal. Until 1917 this line had been also carried on in a very small way, the general policy being to mate the son of a non-broody bird to non-broodies, on the hypothesis that broodiness is a simple Mendelian dominant, and non-broodiness a recessive. As a result of the early matings a male was obtained that appeared to be a homozygous recessive, since he threw no broodies from non-broody mothers. In 1917 this male, No. 3003, with his son, No. 5470 out of a non-broody hen, and grandson, No. 9752 (mother broody once in her third year), also supposed to be homozygous recessives, were mated to all the non-broody hens available. Some of these, however, became broody the second year. The results of the experiment, given in Tables IV and V, show that non-broodiness is not always a simple Mendelian recessive, since the son and grandson failed to breed true, even with those birds that never became broody. This

Table IV. — *The Progeny of Three Supposedly Non-broody Males distributed according to their Mother's Broody History.*

Male.	Mothers not Broody.			Mothers known to be Broody after Pullet Year.			Mothers Broody in Pullet Year.		
	Number of Mothers.	Daughters not Broody.	Daughters Broody.	Number of Mothers.	Daughters not Broody.	Daughters Broody.	Number of Mothers.	Daughters not Broody.	Daughters Broody.
No. 3003, ...	4	19	0	-	-	-	1	4	1
No. 5470 (son of No. 3003),	3	9	1	1	4	4	-	-	-
No. 9752 (son of No. 5470),	6	27	9	1	1	0	4	29	7

TABLE V. — *"Non-broody" Lines, 1917–18.*

[Daughters of males No. 3003, No. 5470 and No. 9752.]

	Number of Daughters.	Daughters not Broody.		Daughters Broody once.		Daughters Broody more than once.		Total Broody Daughters.	
		Number.	Per Cent.	Number.	Per Cent.	Number.	Per Cent.	Number.	Per Cent.
Mothers not broody in pullet year.	72	58	80.55	9	12 50	5	6.94	14	19 44
Mothers broody once in pullet year.	34	28	82.35	1	2.94	5	14.71	6	17.65
Totals,	106	86	81.13	10	9.43	10	9.43	20	18 87

conclusion is supported by the ratios observed in other matings which have already been commented upon. However, the amount of broodiness in the first laying year is much reduced compared with the flock from which it originated, the data on this point being given in Table VII, Table VIII, item 4, and Table IX. A comparison with the published results of the laying contest at the Connecticut Agricultural Experiment Station shows that our foundation stock had broodiness developed to a higher degree than any of the breeds studied at Storrs, and that our non-broody

TABLE VI. — *Broodiness in the Several Breeds at the Storrs Contest of 1915–16, compared with Three Flocks at the Massachusetts Agricultural Experiment Station.*

Breeds.	Number of Birds.	Broody.		Average number of Times Broody per Broody Hen.	Average Number of Times Broody for All Birds in Flock.	Average Number of Days in Broody Period.	Average Number of Days spent in Broodiness by each Broody Hen.	Average Number of Days spent in Broodiness per Hen, per Year, all Birds included.
		Number.	Per Cent.					
Storrs.								
Plymouth Rocks,	151	67	44.4	2.8	1.2	21.2	59 9	26.6
Wyandottes,	151	87	57 6	2.5	1.4	19.4	47.6	27.4
Rhode Island Reds,	183	120	65 6	2.8	1.8	21.3	60 2	39.5
White Leghorns,	315	43	13.6	1.3	.2	22 7	29.6	4.0
Massachusetts.								
Rhode Island Reds, 1912 13.	125	112	89.6	4.4	3.9	19.7	74.8	65.8
Rhode Island Reds, 1913 14.	78	71	91.0	5.4	4.9	16.3	78.8	68.7
Rhode Island Reds, 1917–18, "non-broody" line.	106	20	18.9	1.9	.4	20.9	37.0	10.6

TABLE VII. — *Number and Per Cent of Birds Broody and not Broody in Pullet Year in Three Flocks of Rhode Island Reds.*

Date.	Total Birds.	Broody.		Not Broody.	
		Number.	Per Cent.	Number.	Per Cent.
1912–13,	125	112	89.60	13	10.40
1913–14,	78	71	91.03	7	8.97
1917–18,	106	20	18.87	86	81.13

lines, derived from this extremely broody stock, exhibited a low degree of broodiness surpassed only by the Leghorns (Table VI). The most significant data on this point are given in the third and last columns of Table VI. Table VII shows the relation between the number of broody birds and those not broody for the flocks of 1912–13, 1913–14 and 1917–18. The flock of 1912–13 was the foundation stock.

Tables VIII and X give a further comparison between the broody birds of the flocks of 1913–14 and 1917–18.

TABLE VIII. — *Statistical Constants for Various Broody Characters for the Flock of 1913–14, and the Non-broody Flock of 1917–18.*

		Number of Instances or Individuals.		Mean.		Standard Deviation.		Coefficient of Variation.	
		1913-14.	1917-18.	1913-14.	1917-18.	1913-14.	1917-18.	1913-14.	1917-18.
1	Number of broody periods per individual.	71	20	5.39±0.23	1.90±0.17	2.87±0.16	1.14±0.12	53.24±3.77	59.78±8.35
2	Length of broody periods (days),	327	34	16.28±0.34	20.91±0.95	9.04±0.24	8.22±0.67	55.60±1.85	39.32±3.68
3	Amount of broodiness in each individual (broodies only) (days).	68	20	78.84±4.03	37.00±3.63	49.27±2.85	24.06±2.57	71.68±5.90	65.02±9.42
4	Amount of broodiness in each individual (entire flock) (days).	78	106	68.73±3.28	10.63±1.08	42.95±2.32	16.46±0.76	62.49±4.50	154.83±17.27
5	Days in initial laying period,	71	20	118.67±4.23	170.50±8.42	52.82±2.99	55.86±5.96	44.51±2.98	32.76±3.85
6	Eggs in initial laying period,	71	20	80.64±2.85	101.50±3.84	35.66±2.02	25.48±2.72	44.22±2.95	25.10±2.84
7	Per cent production in initial laying period.	71	20	67.89±0.99	61.00±1.68	12.38±0.70	11.17±1.19	18.24±1.07	18.31±2.02
8	Days in each laying period,	327	34	18.84±0.40	36.85±2.98	10.85±0.29	25.80±2.11	57.60±1.96	70.00±8.06
9	Eggs in each laying period,	327	34	13.96±0.19	21.26±1.52	5.21±0.14	13.12±1.07	37.32±1.11	61.72±6.70
10	Per cent production in each laying period,	327	34	78.41±0.53	64.91±3.09	14.24±0.38	26.70±2.18	18.16±0.49	41.13±3.89
11	Time spent in laying periods annually by each individual (days).	68	20	90.75	62.75	–[1]	–[1]	–[2]	–[3]
12	Average length of broody cycle (days),	327	34	35.02±0.56	57.71±2.98	15.15±0.40	25.72±2.10	43.26±1.34	44.57±4.31
13	Per cent production in broody cycle,	327	34	41.50±0.43	35.94±1.54	11.55±0.30	13.29±1.09	27.83±0.79	36.98±3.41

[1] Standard deviation not calculated. [2] Range 9–188. [3] Range 16–114.

DEFINITION OF TERMS USED IN TABLE VIII.

2. In reckoning the number of days in a broody period the first day without production is taken as the first broody day, while the last day counted is the day before production begins again. The object here is to measure the length of the non-productive period originating with broodiness, but not the intensity of broodiness itself. This definition includes instances in which the resumption of production is delayed long after its normal time because of the interference of factors not concerned with broodiness. Some limitation to the number of days included in the non-productive period is desirable, but the only one employed thus far is the exclusion of broody periods that end the annual cycle of production, and whose length cannot be ascertained.

5, 6, 7. The initial laying period begins with the first egg laid, and ends with the last egg laid before the first broody period.

8, 9, 10. A laying period begins with the first egg laid after a broody period, and ends with the last egg laid before the subsequent broody period.

12, 13. A broody cycle is defined as a broody period plus the following laying period. The incomplete cycles formed by a terminal broody period are rejected in calculating the constants. It is, of course, possible to treat the broody cycle somewhat differently, by defining it as a laying period plus the subsequent broody period. Biometrical constants were calculated for each method of treatment, but since the results proved to be essentially the same, if the initial cycle is omitted, only one set of constants is given in the table.

Constants differing slightly from those given in the table are obtained, if, instead of employing each instance separately in the calculations, the average for each individual bird is employed. Whether the instance or the average for each individual bird should be used in calculating the constants depends on which one occupies the center of interest, but whichever method is used, the primary purpose for which this table is presented is not affected. The inconsistencies in the number of individuals occur because it is often possible to determine a character in one individual but not in another. Thus, every bird that becomes broody can be counted, but if a bird becomes broody but once, and does not lay again until the following year, the length of her broody period cannot be measured, and so is omitted in calculating the constants.

Taking the means (Table VIII) as the basis of comparison, it is clear that the birds of the "non-broody" lines becoming broody in 1917–18 had the character much less intensely developed than the broodies of the flocks of 1912–13 and 1913–14 from which they originated. The mean number of times each broody bird became broody is 1.90 against 5.39. Though the average length of each broody period is longer (Table VIII), the total time spent in broodiness by each broody bird is about one-half that of the broodies of the flock of 1913–14. If the entire flocks of each year (*i.e.*, if the non-broody birds are included in calculating the means) are compared with each other the following significant results are obtained (Table IX): —

TABLE IX. — *A Comparison of the Amount of Broodiness in the Foundation Flock, 1912–13, and their Immediate Unselected Descendants, 1913–14, with their Descendants selected for the Absence of Broodiness, 1917–18.*

DATE.	Number of Birds.	Mean Number of Days spent in Broodiness.	Mean Number of Times Broody.
1912–13,	125	65 81	3.88
1913–14,	78	68.73	4 91
1917–18,	106	10.63	.36

A comparison between the two flocks in respect to egg production (Table VIII) shows that while the 1917–18 flock laid somewhat less rapidly than the 1913–14 flock, the first broody period came later in life (Table X). The mean date of the first broody period is April 18 for the 1913–14 flock, and June 7 for the 1917–18 flock. The 1917–18 flock has a slower rate of production, as shown by the lower percentage production in the initial laying period as well as the later laying periods. On the other hand, the length, both of laying periods and broody periods, is longer

TABLE X. — *Seasonal Distribution of Broodiness in the Flock of 1913-14, and in the Broodies occurring in the Non-broody Lines, 1917-18.*

	Month.	Month in which Individual Broody Periods begin.				Month in which First Broody Period of Each Individual begins.				Month in which Last Broody Period of Each Individual begins.				Month in which Median Broody Period of Each Individual begins.			
		1913-14.		1917-18.		1913-14.		1917-18.		1913-14.		1917-18.		1913-14.		1917-18.	
		Number.	Per Cent.	Number.	Per Cent.	Number.	Per Cent.	Number.	Per Cent.	Number.	Per Cent.	Number.	Per Cent.	Number.	Per Cent.	Number.	Per Cent.
1	November,	-	-	-	-	-[1]	-[1]	-	-	-	-	-	-	-	-	-	-
2	December,	5	1.30	-	-	5	7.04	-	-	-	-	-	-	-	-	-	-
3	January,	4	1.04	-	-	3	4.23	-	-	-	-	-	-	-	-	-	-
4	February,	8	2.08	-	-	3	4.23	-	-	-	-	-	-	-	-	-	-
5	March,	19	4.94	-	-	10	14.08	-	-	-	-	-	-	-	-	-	-
6	April,	41	10.68	4	10.53	21	29.58	4	20.00	-	-	-	-	.5	.70	.5	2.50
7	May,	67	17.45	11	28.95	16	22.54	8	40.00	3	4.23	5	25.00	10.5	14.79	6.0	30.00
8	June,	64	16.67	6	15.79	9	12.68	2	10.00	4	5.63	3	15.00	34.0	47.89	5.0	25.00
9	July,	53	13.80	8	21.05	2	2.82	3	15.00	2	2.82	5	25.00	18.0	25.35	5.5	27.50
10	August,	48	12.50	4	10.53	-	-	3	15.00	6	8.45	2	10.00	5.0	7.04	2.0	10.00
11	September,	43	11.20	4	10.53	1	1.41	-	-	26	36.62	4	20.00	2.0	2.82	.5	2.50
12	October,	25	6.51	1	2.63	-	-	-	-	23	32.39	1	5.00	-	-	.5	2.50
13	November,	7	1.82	-	-	1	1.41	-	-	7	9.86	-	-	1.0	1.41	-	-
	Totals,	384	99.99	38	100.01	71	100.02	20	100.00	71	100.00	20	100.00	71.0	100.00	20.0	100.00

[1] Very few birds laying.

in this flock than in that of 1913–14. Just what this means is uncertain. The longer laying periods may be taken as resultant of the reduced tendency toward broodiness, but this is not true for the longer broody periods. The latter may be connected with the slower rate of production.

The experiments in eliminating broodiness are being continued, but a change in the plan of the experiment, to permit of the fusion of the non-broody line with another line known as the high-producing line, has been made. The fusion appears at date of this writing to be accomplished.

Broodiness, in its various sub-characters and in the associated periods of egg production, is decidedly variable as judged by the several coefficients of variation given in Table VIII. Some of the sub-characters are much more variable than others. While some of the characters associated with broodiness are of the same order of variability in the two flocks studied, others are quite unlike, sometimes one and sometimes the other flock being the more variable. The details are best obtained from Table VIII.

Relation between Birds of a Low Degree of Broodiness and Absence of Broodiness.

Some evidence exists that birds that become broody once during the pullet year are not genetically different from those that do not become broody, since the number of broody offspring from each sort of female is approximately the same, as is shown in Table XI. On the other hand,

Table XI. — *A Comparison between the Number of Broody Offspring from Non-broody Mothers with the Number from Mothers Broody once, the Sires being the Same for Both Lots of Offspring.*

	Number of Mothers.	Broody Offspring.		Non-broody Offspring.	
		Number.	Per Cent.	Number.	Per Cent.
Not broody,	15	14	19 45	58	80.55
Broody,	3	6	17.65	28	82 35

the daughters of birds broody once are somewhat more broody than the daughters of birds not broody at all, as shown in Table XII, which gives a comparison between 14 broody daughters of non-broody mothers and 6 broody daughters of mothers that became broody once, the sires being the same for both lots. It is shown by the per cent production, for both the initial laying period and the subsequent laying periods, that the two sets of birds are about equal in their ability to produce eggs. The daughters whose mothers became broody once were, however, somewhat more broody than the daughters of hens that did not become broody at all, as shown by the length of the initial laying period, the number of broody periods per individual, and the length of the broody periods. Though

in this experiment the daughters of non-broody hens are less broody than the daughters of hens broody once, it would be unwise to generalize such a conclusion, because of the very small number of individuals involved.

TABLE XII. — *A Comparison of the Amount of Broodiness in the Daughters of Non-broody Hens with those whose Mothers became Broody once.*

	Mothers not Broody in Pullet Year.		Mothers Broody once in Pullet Year.	
	Number of Instances or Individuals.	Mean.	Number of Instances or Individuals.	Mean.
Days of broodiness per individual,	14	31 64	6	49.50
Days in each broody period,	22	18 26	12	24.25
Broody periods per individual,	14	1.79	6	2.17
Days in initial laying period,	14	181 36	6	145.67
Eggs laid in initial laying period,	14	106 93	6	85.83
Per cent production in initial laying period per individual.	14	60.86	6	60.27
Days in each laying period,	22	38 23	12	34.50
Eggs laid in each laying period,	22	21.95	12	19.83
Per cent production in each laying period,	22	65 20	12	64.70
Eggs in each laying period per individual,	14	25.44	6	21.37

Since some birds become broody in their second or third laying years that did not become broody in the first year, the question may be raised as to whether or not a hen may ever be so constituted that it is impossible for her to become broody. We have kept a few hens for four years without evidence of broodiness, but this may not mean that these birds might not have become broody if the proper stimulus had existed. There is the further question as to whether the designation "non-broody" has been accurately used for birds not broody in their pullet year. It might be better to regard such cases as instances of delayed broodiness rather than of the actual absence of broodiness. The delay in the appearance of broodiness in some individuals certainly complicates matters greatly.

THE INTERRELATION OF SEVERAL BROODY CHARACTERS.

The interrelations of several of the broody characters have been studied in the 1913-14 flock by means of the coefficient of correlation. It should, perhaps, be pointed out that the coefficient of correlation does not measure the relationship between the characters as such, but relationship between the numerical occurrence of such characters in the flock studied. This limitation in the use of the coefficient of correlation is often forgotten. Thus it is found that r between number of eggs laid in a year and total days spent in broodiness is $+.1677 \pm .0742$. This value, as shown by

its large probable error, is not significant statistically, but, ignoring the error, may perhaps indicate that broodiness is an advantage, since, on the average, those birds spending the most time in broodiness are the heaviest layers. On the contrary, it is known from a study of other data that the very best layers cannot spend much time in broodiness. The interpretation we give this value is that those birds whose laying year begins earliest and stops latest get in more broody periods, other things being equal, than birds whose laying year is shorter.

If an index of production of high value is desired, it is found in the initial laying period, for here the correlation between the length of the period and number of eggs produced is very high, viz., $+.8843 \pm .0210$, a value, moreover, that indicates good homogeneity in rate of production in this flock.

In this flock there is a pronounced negative correlation between egg production during the laying periods and number of broody periods, the coefficient of correlation being $-.3453 \pm .0716$, indicating that those birds that are very broody tend to lay less eggs between broody periods than those having a less number of broody periods. On the other hand, there is no relation between the average (*i.e.*, for one individual) length of laying periods or the eggs produced in such periods and average length of broody periods, since in the first case $r = -.0130 \pm .0818$, and in the second case $r = -.0013 \pm .0818$.

While the above statements hold true for average values, if the coefficient of correlation is determined between the length of a laying period or its egg production and the length of the broody period immediately subsequent thereto, a marked negative correlation is found, being $-.2899 \pm .0415$ in the first instance, and $-.3715 \pm .0345$ in the second. The disagreement between the values obtained when each laying period is correlated with its subsequent broody period, and that found when the average value for each bird is used, is due to a shortening of the laying period and a lengthening of the broody period as the season progresses. This is clearly shown on the individual records.

If, instead of taking a laying period and its subsequent broody period, a broody period is paired with the laying period following, little or no relationship is indicated, for r between length of broody period and subsequent laying period is $-.0222 \pm .0388$, while between length of broody period and subsequent egg production it is only slightly greater, being $-.0799 \pm .0372$.

The interrelationships discussed in the two paragraphs preceding may perhaps be interpreted to mean that heavy laying tends to suppress broodiness, or, at least, that in the flock studied, those birds that laid most heavily had shorter broody periods than those laying less heavily, the tendency to heavy production in such birds enabling them to get back more quickly into production than those in which the tendency was less strong. Longer broody periods, however, and their accompanying element of rest did not conduce to heavier production, a view contrary to that held by most poultrymen.

Summary and Conclusions.

The working hypothesis is adopted that —

1. Broodiness depends upon the presence of a "complete mechanism" in the individual, from which it follows that the absence of broodiness depends upon the loss of some essential part of this mechanism, or upon its inhibition by some secondary factor.

2. The inheritance of broodiness may be expected to vary from flock to flock.

3. In the flocks studied, non-broodiness appears to result from the loss of one or both of two genes from the complete germinal complex, while there is some evidence that a dominant inhibitor may also exist in the germ plasm of these flocks.

4. By suitable breeding methods it has been possible to develop quickly a strain of low degree of broodiness from a strain with a very high degree of broodiness.

5. Statistical constants for certain broody characters are given.

Literature Cited.

Bateson, W., 1902. Experiments with Poultry. Reports to the Evolution Committee of the Royal Society. Report I, pp. 87–124.

Gerhartz, H., 1904. Ueber die zum Aufbau der Eizelle Notwendige Energie. (Transformationsenergie) Pfluger's Arch. Bd. 56, pp. 1–224.

Goodale, H. D., 1918. Internal Factors influencing Egg Production in the Rhode Island Red Breed of Domestic Fowl. Am. Nat, Vol. LII, pp. 65–94, 209–232, 301–321.

Herrick, F. H., 1907*a*. Analysis of the Cyclical Instincts of Birds. Science, N. S., Vol. XXV, pp. 725, 726.

——, 1907*b*. The Blending and Overlap of Instincts. Science, N. S., Vol. XXV, pp. 781, 782.

Hurst, C. C., 1905. Experiments with Poultry. Reports to the Evolution Committee of the Royal Society. Report II, pp. 131–154.

Kirkpatrick, W. F., and Card, L. E., 1917. Fifth Annual International Egg-laying Contest. Bulletin No. 89, Storrs Agricultural Experiment Station, pp. 257–301.

Pearl, R., 1914. Studies on the Physiology of Reproduction in the Domestic Fowl. VII. Data regarding the Brooding Instinct in its Relation to Egg Production. Journal An. Beh., Vol. 4, pp. 266–288.

BULLETIN No. 200.

DEPARTMENT OF CHEMISTRY.

THE NUTRITIVE VALUE OF CATTLE FEEDS.

2. OAT BY-PRODUCTS FOR FARM STOCK.

BY J. B. LINDSEY AND C. L. BEALS.

A. The Process of Manufacture.

Oat feed is the residue from the oat meal mills engaged in the preparation of oat products for human consumption.

In the milling process the first step consists in separating the light and double oats and other cereal seeds, as well as sticks and straw, from the oats suitable for human consumption. These latter oats are divided into two or more grades, depending upon size, in order to gain efficiency in milling, and are then roasted or dried in open pans over fire with constant stirring, in order to drive off as much moisture as possible. From the roasters the oats are run over coolers and dusters, and then to the stones which remove the hulls. This latter process, called the first milling or hulling, does not remove all of the hulls, and the unhulled oats are subjected to a second milling to complete the process.

Mill run oat feed contains the hulls, usually reground, together with the middlings and dust removed in the first milling. The residue from the second milling contains a much larger proportion of middlings, and, together with some middlings recovered in cleaning the rolled oats, is used in calf meals and poultry feeds, and is not returned to the oat feed.[1] It is understood that *mill run oat feed*, as above described, should be a comparatively uniform product, especially as produced at the larger plants in the United States. On the other hand, small Canadian mills, because of a less efficient process of separation, are likely to put out an oat feed of better quality than the average run from the larger American mills.

[1] One large manufacturer states that in its process the middlings and dust from the second milling are also incorporated in the oat feed, and that the material used in calf and pig meals represents the fine oat particles and chips made in cutting groats or shelled oats, together with the fine flakes that come from the rolled oat aspirators, and also the pieces of groats which are unsatisfactory for rolling on account of being broken. It seems reasonable to assume that the process of manufacture may vary somewhat in different establishments.

B. Analyses of Oat By-Products.

In view of the constant increase in the cost of hay and all kinds of concentrates, it was believed that a study of the value of oat by-products was worth while. A visit was therefore made by Mr. P. H. Smith to one of the mills of the Quaker Oats Company and of the H-O Company, the process of manufacture observed, and samples secured for analysis, which were declared by the manufacturers and believed by us to be representative. In addition, several lots of oat feed were shipped us at our request for the purpose of conducting digestion and feeding experiments. The analyses of all of these samples follow: —

Table I. — *Composition of Oat By-Products.*

(*a*) *Oat Hulls.*

Sample No.	Source.	Water.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.	Total.
1	H-O Company (unground), . .	3.82	6.65	.96	33.18	54.99	.40	100
2	Quaker Oats Company (ground), .	5.04	6.15	2.01	31.08	54.78	.94	100
	Average, ...	4.43	6.40	1.49	32.13	54.88	.67	100

(*b*) *Oat Middlings and Dust.*

Sample No.	Source.	Water.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.	Total.
1	H-O Company (first break), . .	4.13	8.00	9.54	23.68	50.57	4.08	100
2	H-O Company (second break), .	5.20	3.40	16.73	5.58	61.14	7.95	100
3	Quaker Oats Company, . . .	5.54	5.94	12.30	15.60	54.97	5.65	100
4	Henry & Morrison,[1] . . .	7.30	3.20	16.30	4.60	61.80	6.80	100

(*c*) *Oat Feed.*

Sample No.	Source.	Water.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.	Total.
1	H-O Company, mill run, . . .	4.24	6.34	6.04	26.65	54.05	2.68	100
2	Quaker Oats Company, mill run, .	5.48	5.95	5.26	27.18	53.98	2.15	100
3	Quaker Oats Company, mill run, .	5.30	6.10	4.65	26.73	55.14	2.08	100
4	Quaker Oats Company, mill run, .	9.53	5.39	5.29	24.17	53.37	2.25	100
5	Quaker Oats Company, mill run, .	7.75	5.91	5.22	24.85	54.04	2.23	100
6[2]	Quaker Oats Company, mill run, .	7.59	6.10	7.12	22.62	53.40	3.17	100
7	Quaker Oats Company, mill run, .	7.03	6.58	6.40	29.82	48.09	2.08	100
8	Quaker Oats Company, mill run, .	7.25	5.86	5.91	26.05	52.80	2.13	100
9	Quaker Oats Company, mill run, .	7.07	5.99	6.00	26.00	52.90	2.04	100
10	Quaker Oats Company, mill run, .	5.48	6.39	5.98	31.85	48.09	2.21	100
11	Quaker Oats Company, mill run, .	7.63	6.24	5.53	27.57	51.04	1.99	100
12	Quaker Oats Company, mill run, .	7.90	5.84	5.04	26.14	53.10	1.93	100
	Average, ...	6.85	6.06	5.70	26.64	52.50	2.24	100

[1] Average of 23 analyses.

[2] Sample No. 6 evidently contains an excess of middlings, and cannot be considered representative.

The results of the analyses of the two samples of oat hulls simply emphasize their very low protein and fat, — 1.49 of protein and .67 of fat, — and their very high fiber content. The fiber percentage multiplied by 3 gives 96.4 per cent of hulls, indicating the presence of very little dust or middlings.

Oat middlings vary somewhat in composition, depending naturally upon the process of separation employed. The higher the fiber content the less completely are the hulls separated. A high grade of middlings such as results from the second break evidently ought to contain not more than 5 to 6 per cent of fiber, and at least 15 per cent of protein.

The oat feed does not vary more in composition than one would expect from a by-product of this sort. Its moisture content is low, due to artificial drying, showing an average of 6.85 per cent. It has relatively little protein, extremes of from 4.65 to 7.12 being noted, with an average of 5.70 per cent. The fiber content is high, due to the large amount of oat hulls; the average percentage of fiber was 26.64. A much higher percentage of fiber than this average would indicate an excess of hulls. Carefully conducted studies[1] have shown that in case of oat by-products the percentage of fiber present multiplied by 3 will give the percentage of oat hulls. The application of this rule to the average analyses of the twelve samples (26.64 x 3 = 80) shows 80 per cent of hulls and 20 per cent of fine material (oat dust and middlings). The fat percentage in the feed is low, as would be expected.

C. Digestibility of Oat By-Products.

The station has made a number of digestion experiments with oat feed, middlings and hulls. Sheep and horses were employed for the purpose. The results only of the experiments are reported in this connection. Sheep would not eat any amount of the oat feed when fed dry, and hence it was necessary to moisten it thoroughly. It was also moistened before being fed to horses.

Table II. — *Digestion Coefficients for Oat By-Products.*

(*a*) *Oat Hulls* (*Sheep*).

Series.	Experiment.	Animal.	Percentages of Ingredients Digested.						Ration Fed.
			Dry Matter.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.	
24, . . .	13	9	31	16	-	50	29	-	500 g. hay+150 g. gluten feed+150 g. oat hulls.
24, . . .	13	11	36	9	12	51	36	14	
Average, . . .			34	13	12	50	33	14	

[1] Landw. Versuchssta. Band XCIV, Heft I and II, pp. 9-40, by H. Neubauer.

TABLE II. — *Digestion Coefficients for Oat By-Products* — Concluded.

(*b*) *Oat Hulls (Horses).*

Series.	Experiment.	Animal.	Dry Matter.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.	Ration Fed.
			Percentages of Ingredients Digested.						
3, ...	4	Joe	24	36	123	28	10	76	8,000 g. hay+2,500 g. brewers' grains +2,000 g. oat hulls.
3, ...	4	Tom	20	33	105	15	11	88	
Average, ...			22	34	?	22	11	82	

(*c*) *Oat Middlings (Sheep).*

Series.	Experiment.	Animal.	Dry Matter.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.	Ration Fed.
X, ...	14	IV	91	31	81	77	97	93	550 g. hay+300 g. oat middlings.
X, ...	14	V	88	30	80	21	94	94	
Average, ...			90	36	80	49	95	93	
Wheat flour middlings for comparison.			82	-	88	36	88	86	

(*d*) *Oat Feed (Horses).*

Series.	Experiment.	Animal.	Dry Matter.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.	Ration Fed.
3, ...	5	Joe	40	13	58	51	36	36	8,000 g. hay+2,500 g. oat feed.
3, ...	5	Tom	43	14	54	55	39	69	
Average, ...			42	14	56	53	38	53	

(*e*) *Oat Feed (Sheep).*

Series.	Experiment.	Animal.	Dry Matter.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.	Ration Fed.
24, ...	12	12	51	92	81	39	45	119	500 g. hay+150 g. gluten feed+150 g. oat feed.
24, ...	12[1]	13	19	52	5	1	19	102	
25, ...	11[1]	9	29	-	18	23	31	185	500 g. hay+150 g. oat feed.
25, ...	11[1]	11	27	-	22	21	32	100	
25, ...	13	9	55	26	86	56	49	43	500 g. hay+150 g. gluten+150 g. oat feed.
25, ...	13	11	51	26	90	43	49	46	
25, ...	18	12	57	69	90	57	52	16	500 g. hay+150 g. oat feed.
25, ...	18	13	47	23	86	53	40	67	
Average, ...			52	-	86	46	48	69	
Timothy hay (for comparison).			55	39	47	51	62	50	
Fine hay (extra) (for comparison).			61	44	55	63	62	48	

[1] Excluded from the average.

The results with oat hulls show that the sheep were able to digest 34 per cent of the hulls, and the horses 22 per cent. The protein and fat content of the hulls is quite small, and the coefficients for these ingredients with both sheep and horses are of no particular account. The sheep digested one-half of the fiber and one-third of the extract matter, while the coefficients obtained with the horses were noticeably less. It is possible that in case of the horses, if the hulls had been fed with a different combination than hay and brewers' grains, the results would have been somewhat more favorable. It has been established, however, that horses are not able to utilize fibrous material as well as are the bovines.

The trial with oat middlings was made at this station a number of years since, and has been published.[1] The sample was found in the Massachusetts markets, and was of excellent quality, containing 16.1 per cent of protein, 2.3 per cent of fiber, and 7 per cent of fat. The results are given here to show how well the animal is able to digest oat middlings when substantially free from fiber.

TABLE III. — *Digestible Matter in 2,000 Pounds.*

(*a*) *Sheep.*

FEED.	Dry Matter.	Protein.	Fiber.	Extract Matter.	Fat.	Total Digestible Matter (Fat × 2.2).	Relative Values: Basis Digestible Matter (Oat Feed 100).
Oat hulls,	649.8	3.6	321.4	362.4	1.8	691.3	75
Oat middlings,	1,668.6	260.8	45.0	1,174.2	126.4	1,758.0	191
Oat feed,	969.6	99.0	245.4	503.6	31.4	917.7	100
Timothy hay (for comparison).	946.0	76.0	284.0	542.0	20.0	946.0	103
Fine hay (extra) (for comparison).	1,073.6	86.0	358.0	546.0	22.0	1,038.0	113

(*b*) *Horses.*

FEED.	Dry Matter.	Protein.	Fiber.	Extract Matter.	Fat.	Total Digestible Matter (Fat × 2.2).	Relative Values: Basis Digestible Matter (Oat Feed 100).
Oat feed,	782.0	64.4	282.0	338.0	24.0	737.2	100
Timothy hay,	756.8	33.6	243.4	410.8	39.4	727.2	98.6

On the basis of the digestion experiments with sheep, it will be seen that oat feed contains 918 pounds of total digestible matter as against 1,758 for oat middlings, 691 for oat hulls, and 946 for timothy hay. Placing oat feed at 100, oat middlings would have a feeding value of 91 per cent more, oat hulls 25 per cent less, and timothy 3 per cent more.

On the basis of digestible organic matter, the oat feed and timothy

[1] Mass. Agr. Expt. Sta., Ann. Rept. 19, p. 114.

appear to have about equivalent feeding values for horses. In place of digestible matter as a measurement of nutritive value, Kellner and also Armsby, as a result of more recent investigations, have adopted the unit of net energy. While recognizing its superiority over digestible matter as a basis for comparison, the writers feel that sufficient data are not available to warrant its use in the case of oat by-products.

D. Oat Feed for Dairy Cows.

Experiments I, II, and III.

In addition to the numerous analyses and digestibility trials with the several oat by-products, it was thought necessary to observe the effect of oat feed upon milk production. Inasmuch as it approximated hay in digestibility, it was fed in comparison with hay. Thus fed, a larger amount could be given daily than if used as a component of a grain mixture.

The experiments, three in number, with eight, four and eleven cows, respectively, were conducted by the usual reversal method. The basal ration consisted of a uniform grain mixture and sufficient of a first quality of cow hay to meet the needs of each animal. In each half of the experiment a definite amount of oat feed *on a dry matter basis* was substituted for a like weight of hay, amounting in case of individual cows to from 6 to 8 pounds daily. It was fed well moistened with water and was readily eaten. The average daily ration fed will be found in Table VIII.

TABLE IV. — *History of the Cows.*

EXPERIMENT I.

NAME.	Age.	Breed.	Calved.	Served.	Milk Yield, Beginning (Pounds).	Fat (Per Cent).
Peggy,	9	G. Jersey,	Aug. 13, 1918	Dec. 26, 1918	18	6.4
190,	7	G. Holstein,	Dec. 3, 1918	Feb. 9, 1919	25	3.8
Colantha II,	4	G. Holstein,	July 22, 1918	Nov. 7, 1918	25	4.5
Red IV,	6	G. Jersey,	Mar. 7, 1919	– –	30	5.0
Fancy IV,	4	G. Jersey,	July 22, 1918	Oct. 30, 1918	16	5.5
Ida II,	6	P. Jersey,	Oct. 27, 1918	Feb. 13, 1919	23	6.0
Samantha III,	6	G. Holstein,	Aug. 26, 1918	Dec. 5, 1918	20	4.7
Betty II,	12	G. Ayrshire,	Jan. 24, 1919	Feb. 19, 1919	30	4.6

EXPERIMENT II.

190,	8	G. Holstein,	Nov. 17, 1919	– –	31	4.4
Cecile II,	7	P. Jersey,	Oct. 12, 1919	– –	21	5.6
Ida II,	7	P. Jersey,	Nov. 22, 1919	– –	30	6.0
Peggy,	10	G. Jersey,	Oct. 9, 1919	– –	23	6.2

EXPERIMENT III.

Cecile II,	7	P. Jersey,	Oct. 12, 1919	Feb. 24, 1920	18	6.2
Diantha II,	3	G. Holstein,	Jan. 22, 1920	– –	34	3.4
Colantha II,	5	G. Holstein,	Aug. 8, 1919	Nov. 3, 1919	33	4.2
Ida II,	7	P. Jersey,	Nov. 22, 1919	Feb. 10, 1919	26	6.2
Samantha III,	6	G. Holstein,	Sept. 12, 1919	Dec. 8, 1919	29	4.0
Colantha,	6	G. Holstein,	Sept. 19, 1919	Feb. 4, 1920	21	4.3
Fancy IV,	5	G. Jersey,	Aug. 10, 1919	Nov. 15, 1919	18	5.5
Eantha,	3	G. Holstein,	Jan. 19, 1919	– –	28	3.6
Samantha IV,	5	G. Holstein,	Aug. 20, 1919	Dec. 4, 1919	32	4.6
Peggy,	10	G. Jersey,	Oct. 9, 1919	Feb. 4, 1919	24	6.4
190,	8	G. Holstein,	Nov. 17, 1919	Jan. 2, 1920	31	4.4
Red IV,	6	G. Holstein,	Jan. 14, 1919	– –	32	4.9

TABLE V. — *Duration of Experiments.*

EXPERIMENT I.

Dates.	Hay Ration.	Hay and Oat Feed Ration.	Weeks Fed.
April 3, 1919, through April 30, 1919,	Fancy IV, Ida II, Samantha III, Betty II,	Peggy, 190, Colantha II, Red IV,	4
May 11, 1919, through June 7, 1919,	Peggy, 190, Colantha II, Red IV,	Fancy IV, Ida II, Samantha III, Betty II,	4

EXPERIMENT II.

Dec. 24, 1919, through Jan. 27, 1920,	Ida II, Peggy,	190, Cecile II,	5
Feb. 8, 1920, through March 13, 1920,	190, Cecile II,	Ida II, Peggy,	5

EXPERIMENT III.

April 1, 1920, through May 5, 1920,	Fancy IV, Eantha, Samantha IV, Peggy, 190, Red IV,	Cecile II, Diantha II, Ida II, Samantha III, Colantha,	5
May 16, 1920, through June 19, 1920,	Cecile II, Diantha II, Ida II, Samantha III, Colantha,	Fancy IV, Eantha, Samantha IV, Peggy, 190, Red IV,	5

Care of the Animals. — The animals were cared for in the usual way, as described in previous experiments.

Sampling Feeds and Milk. — The hay was sampled three times during each half of the trial, by taking forkfuls here and there, running the same through a power cutter, sub-sampling, and placing the sub-samples in glass-stoppered bottles which were brought to the laboratory at once, dry matter determinations made, and composite samples analyzed. The grain mixtures were sampled each time a new lot was mixed, and the samples placed in glass-stoppered bottles for analysis. The oat feed was sampled at regular intervals during the experiment.

The milk was sampled for five consecutive days for two or three weeks during each half of the trial, preserved with formalin, and analyzed for total solids and for fat by the Babcock method. The usual method of sampling was followed as described in previous experiments.

TABLE VI. — *Grain Mixtures fed (Pounds).*

Experiment I.		Experiment II.		Experiment III.	
Coconut meal,	50	Coconut meal,	40	Coconut meal,	30
Velvet bean feed,	20	Gluten feed,	30	Gluten feed,	10
Wheat bran,	20	Wheat bran,	30	Wheat bran,	20
Linseed meal,	10			Corn meal,	30
				Peanut meal,	10

Notes of the Experiment. — In Experiment I, a preliminary test of the oat feed used showed it to contain 4.95 per cent of protein and 26.89 per cent of fiber, and it was regarded as a representative lot. The final analysis, however, made from a number of different samples, gave 7.12 per cent of protein and 22.62 per cent of fiber, indicating the presence of an undue amount of oat middlings. The results of this experiment are reported, but they are not included in the average.

In Experiment III, twelve cows were employed, but during the progress of the experiment Colantha II showed such an abnormal milk shrinkage that she could not be continued, and the experiment was completed with eleven cows.

TABLE VII. — *Chemical Analysis of Feeds used (Per Cent).*

Experiment.	Feed.	Water.	Ash.	Crude Protein.	Fiber.	Extract Matter.	Fat.
I,	Hay,	10.00–11.63 10.85	5.34	7.27	26.09	47.81	2.64
	Oat feed,	7.59	6.10	7.12	22.62	53.40	3.17
	Grain mixture,	10.24	5.62	18.71	8.90	50.19	6.34
II,	Hay,	9.50–10.25 9.72	5.62	8.42	29.49	44.22	2.53
	Oat feed,	7.63	6.24	5.53	27.57	51.04	1.99
	Grain mixture,	11.08	5.64	20.90	9.10	48.24	5.04
III,	Hay,	10.96–11.96 11.46	4.23	6.98	26.70	48.08	2.55
	Oat feed,	7.90	5.84	5.04	26.14	53.10	1.93
	Grain mixture,	11.77	4.28	18.18	5.87	53.86	6.07

The hay was of good to excellent quality. It contained a considerable proportion of the finer grasses, together with some timothy and clover, and was usually cut before it was too ripe. Its fiber percentage was not unduly high, and it contained a reasonable amount of protein. Attention has already been called to the fact that the first sample of oat feed contained too large a per cent of middlings to be representative, as is indicated by its relatively low fiber and high protein and fat.

The grain mixtures contained the desired amounts of the several ingredients, and were of satisfactory composition.

A study of Table VIII shows that the average cow received the same amount of grain daily during each experiment. In case of roughage, from 6 to 8 pounds of oat feed were substituted for a like amount of hay *on a dry matter basis.* Because of the dryer condition of the oat feed, it took .5 of a pound less of oat feed in its natural condition to replace a like amount of hay, *e.g.*, 6.5 pounds of oat feed in place of 7 pounds of hay, or 8 pounds of oat feed in place of 8.5 pounds of hay, or 7.64 pounds of oat feed in place of 8.14 pounds of hay. If 8 pounds of hay in its natural state had been fed in place of 8 pounds of oat feed in its natural state the results should have been slightly more favorable to the oat feed.

Table VIII. — *Average Ration Consumed per Cow (Pounds).*

Experiment I.

Number of Cows.	Character of Ration.	Hay.		Oat Feed.		Grain Mixture.	
		Total per Cow.	Daily per Cow.	Total per Cow.	Daily per Cow.	Total per Cow.	Daily per Cow.
8, ...	Oat feed, . .	392 00	14 00	182.00	6 50	252 00	9 00
8, ...	Hay, . . .	588.00	21 00	–	–	252 00	9 00

Experiment II.

4, ...	Oat feed, . .	402 00	11 50	280.00	8 00	324 00	9.25
4, ...	Hay, . . .	700.00	20 00	–	–	324 00	9 25

Experiment III.

11, ...	Oat feed, . .	447.05	12.77	270.45	7.64	308.64	8 82
11, ...	Hay, . . .	731.82	20.91	–	–	308.64	8.82

Table IX. — *Estimated Dry and Digestible Nutrients in Average Daily Rations (Pounds).*

Experiment I.

Character of Ration.	Dry Matter.	Digestible Nutrients.					Nutritive Ratio.
		Protein.	Fiber.	Extract Matter.	Fat.	Total.	
Oat feed, ...	26 28	2.34	3.05	9 31	.86	15.57	1:6 06
Hay, ...	26.73	2.24	3.59	9.74	.77	16 34	1:6.71

Experiment II.

Oat feed, ...	25 98	2.55	3.56	8.86	.61	15.58	1:54 00
Hay, ...	26.27	2 56	4 13	9 24	.60	16 53	1:57 00

Experiment III.

Oat feed, ...	26.22	2 11	3.24	9.89	.71	15.95	1:6 96
Hay, ...	26.32	2.09	3.71	10.33	.71	16 84	1:7 52

The above figures are based upon analyses and average digestion coefficients. On this basis, in each of the three experiments, the hay ration appears to have contained a little more total digestible nutrients than the oat feed ration. The two rations in each experiment contained about the same amounts of protein and fat.

TABLE X. — *Total Yields of Milk and Milk Ingredients.*

EXPERIMENT I.

Oat Feed Ration.

Cows.	Milk produced (Pounds).	Total Solids (Per Cent).	Total Solids (Pounds).	Fat (Per Cent).	Fat (Pounds).
Peggy,	556.7	16.18	90.07	7.23	40.25
190,	747.1	12.89	96.30	4.53	33.84
Colantha II,	649.7	14.80	96.16	5.47	35.54
Red IV,	998.7	14.19	141.72	5.55	55.43
Fancy IV,	443.6	15.18	67.34	5.99	40.34
Ida II,	681.9	15.00	102.29	6.25	63.93
Samantha III,	560.0	13.92	77.95	5.08	39.60
Betty II,	848.1	13.37	113.39	4.93	55.90
Totals,	5,485.8	–	785.22	–	364.83
Averages,	–	14.31	–	6.65	–

Hay Ration.

Cows.	Milk produced (Pounds).	Total Solids (Per Cent).	Total Solids (Pounds).	Fat (Per Cent).	Fat (Pounds).
Peggy,	492.9	16.10	79.36	6.78	53.81
190,	710.2	12.75	90.55	4.39	39.75
Colantha II,	447.0	14.78	66.07	5.44	35.94
Red IV,	860.6	13.39	115.23	5.50	63.38
Fancy IV,	455.2	15.43	70.24	5.93	26.99
Ida II,	695.1	15.35	106.70	6.24	43.37
Samantha III,	591.7	14.21	84.08	5.32	31.48
Betty II,	884.0	13.78	121.82	4.93	43.58
Totals,	5,136.7	–	734.05	–	338.30
Averages,	–	14.29	–	6.58	–

TABLE X. — *Total Yields of Milk and Milk Ingredients* — Continued.

EXPERIMENT II.

Oat Feed Ration.

Cows.	Milk produced (Pounds).	Total Solids (Per Cent).	Total Solids (Pounds).	Fat (Per Cent).	Fat (Pounds).
190,	1,115.4	12 53	139.76	4 33	48 30
Cecile II,	695 1	14 79	105.59	5 86	41 83
Ida II,	877 2	14.85	130 26	6 00	52 63
Peggy,	806 0	15 12	121 88	6 43	51 83
Totals,	3,512 6	–	497.49	–	194.59
Averages,	–	14.16	–	5.54	–

Hay Ration.

190,	1,060.9	12.66	134.31	4.25	45 09
Cecile II,	640.6	15.33	98.20	6 24	39 97
Ida II,	973 6	14.93	145.36	6.09	59 29
Peggy,	799.3	15 17	121.25	6.50	51 95
Totals,	3,474.34	–	499.12	–	196 30
Averages,	–	14.37	–	5.65	–

EXPERIMENT III.

Oat Feed Ration.

Cecile II,	612 0	15.37	94.06	6 37	38.98
Diantha II,	1,164 5	12.11	141.02	3.88	45.18
Ida II,	858.9	14.92	128.15	6.03	51.79
Samantha III,	873.3	13 26	115.80	4.70	41 05
Colantha,	802 7	12.78	102.59	4 50	36.12
Fancy IV,	586.0	14.83	86.90	5 65	33 11
Eantha,	833.5	12.53	104.44	4.07	33.92
Samantha IV,	963 2	13.25	127.62	4 84	46 62
Peggy,	757.7	15.19	115.09	6.30	47.74
190,	915.4	13.05	119.46	4.44	40 64
Red IV,	1,009 6	14 45	145.89	5.60	56 54
Totals,	9,376.8	–	1,281.02	–	471.69
Averages,	–	13 66	–	5 03	–

TABLE X. — *Total Yields of Milk and Milk Ingredients* — Concluded.

EXPERIMENT III — *Concluded.*

Hay Ration.

Cows.	Milk produced (Pounds).	Total Solids (Per Cent).	Total Solids (Pounds).	Fat (Per Cent).	Fat (Pounds).
Cecile II,	583.6	15.22	88.82	6.07	35.42
Diantha II,	1,081.1	11.67	126.16	3.52	38.05
Ida II,	791.9	14.43	114.27	5.54	43.87
Samantha III,	597.9	13.79	82.45	5.01	29.95
Colantha,	724.5	12.71	92.08	4.74	34.34
Fancy IV,	606.0	14.98	90.78	5.88	35.63
Eantha,	853.1	12.58	107.32	4.23	36.09
Samantha IV,	1,047.3	13.30	139.29	4.76	49.85
Peggy,	744.3	15.29	113.80	6.59	49.05
190,	967.3	13.08	126.52	4.52	43.72
Red IV,	1,029.5	14.04	144.54	5.56	57.24
Totals,	9,026.5	–	1,226.03	–	453.21
Averages,	–	13.58	–	5.02	–

TABLE XI. — *Summary of Yields (Pounds).*

EXPERIMENT.	Character of Ration.	Number of Cows.	Milk produced.	Total Solids.	Total Fat.
I,	Oat feed,	8	5,485.8	785.22	364.83
	Hay,		5,136.7	734.05	338.30
II,	Oat feed,	4	3,512.6	497.49	194.59
	Hay,		3,474.3	499.12	196.30
III,	Oat feed,	11	9,376.8	1,281.02	471.69
	Hay,		9,026.5	1,226.03	453.21
Totals, II and III,	Oat feed,	15	12,889.4	1,778.51	666.28
	Hay,		12,500.8	1,725.15	649.51

TABLE XII. — *Percentage Increase Oat Feed Over Hay.*

EXPERIMENT.	Milk produced.	Total Solids.	Total Fat.
I,	6.7	7.0	7.8
II,	1.1	-	0.9
III,	3.9	4.5	4.1
Totals, II and III,	3.1	3.0	2.5

The results of Experiment I have been omitted from the average because of the variation of the lot of oat feed from the recognized standard. The results of Experiments II and III with four and eleven cows, respectively, covering periods of five weeks each, show that the substitution of from 7 to 8 pounds of dry matter in the form of oat feed for a like amount of dry matter in the form of a good quality of hay (8 pounds and 7.64 pounds of oat feed in place of 8.5 pounds and 8.14 pounds of hay in natural condition) produced substantially 3 per cent more milk and milk ingredients.

TABLE XIII. — *Gain or Loss in Live Weight (Pounds).*

EXPERIMENT.	GAIN.		LOSS.		NET.	
	Oat Feed Ration.	Hay Ration.	Oat Feed Ration.	Hay Ration.	Oat Feed Ration.	Hay Ration.
I,	79	38	56	78	23+	40—
II,	12	15	47	53	35—	38—
III,	231	180	37	50	194+	130+
Averages, II and III,	-	-	-	-	159+	92+

During the experiments the cows on the two different rations showed little change in weight. Our object in each experiment was to feed them a little less than was required for maintenance and milk yield, in order to get, so far as possible, the full effect of each ration. In Experiment III some of the cows were considerably advanced in lactation, at which time they are prone to increase somewhat in weight.

E. Oat Feed for Horses.

Oat feed has been fed to a pair of farm horses, Joe and Chub, at intervals for a period of five months, beginning in early May. The horses had been used for digestion work during the winter, and it was necessary during the early spring to bring them on to a full day's work by degrees. They were employed in plowing, harrowing, drawing manure, mowing, and in similar work for nine hours daily during five and one-half days in each week.

The oat feed was substituted for the hay, at first in the proportion of 5 pounds, and later 6 pounds, daily.

The "grain mixture" consisted of 10 pounds of cracked corn, 1 pound of wheat bran, and 1 pound of cottonseed meal. The object of feeding the cottonseed was to furnish some extra protein in the ration, and to note if any objectionable effect occurred from its use. The wheat bran was used not only for its nutritive value, but because of its gentle laxative effect.

Table XIV. — *Daily Rations consumed (Pounds).*

Periods.	Joe.				Chub.			
	Grain Mixture.	Whole Oats.	Hay.	Oat Feed.	Grain Mixture.	Whole Oats.	Hay.	Oat Feed.
May 3–June 13,	12	5	15	–	11	5	9	5
June 14–July 11,	12	5	10	5	11	5	14	–
July 12–August 8,	12	5	15	–	11	5	8	6
August 9–September 12,	12	5	9	6	11	6	14	–

The table shows that each horse received daily 12 and 11 pounds, respectively, of the grain mixture of corn, cottonseed and bran. This amount was divided into two feeds, and given in the morning and evening. At noon each horse received 5 pounds of oats. From May 3 to June 13, inclusive, Joe received daily 15 pounds of hay and no oat feed, while Chub received 9 pounds of hay and 5 pounds of oat feed. From June 14 to July 11, inclusive, the conditions for the coarse feed were reversed, Joe receiving the hay and oat feed and Chub the hay only. Conditions were again reversed July 12–August 8, and again August 9–September 12, so that during each period from May 1 through September 12 one of the horses was receiving hay for roughage and the other a limited amount of hay and 5 or 6 pounds daily of the oat feed. The latter was well moistened before being fed, and given in three portions. The horses objected a little to the oat feed at first, but soon learned to eat it readily.

Table XV. — *Estimated Digestible Nutrients consumed Daily (Pounds).*

Ration fed.	Protein.	Total (Fat × 2.2).	Nutritive Ratio.
15 pounds hay, 5 pounds oats, 10 pounds cracked corn, 1 pound cottonseed meal, 1 pound wheat bran.	2.40	20.20	1:7.4
9 pounds hay, 6 pounds oat feed, 5 pounds whole oats, 10 pounds cracked corn, 1 pound cottonseed meal, 1 pound wheat bran.	2.30	19.50	1:7.5
Standards for comparison: —			
Kellner's (moderate work),	2.00	17.70	1:8.0
Kellner's (hard work),	2.80	24.50	1:7.7
Lavalard's (moderate work),	1.86	18.10	1:8.3
Grandeau's (moderate work),	2.20	17.96	1:7.9

The horses approximated 1,400 pounds each in weight. The above figures show the estimated digestible nutrients that were fed daily and the standard requirements for horses weighing 1,400 pounds, as stated by different authorities. It seems clear that the horses, which were doing moderately hard work, were receiving sufficient digestible protein and total nutrients. It is doubtful if they would have kept in good condition with less food.

Table XVI. — *Weights of Animals.*

Joe.

Dates.	Weeks.	Character of Ration.	Weight, Beginning.	Weight, End.	Gain or Loss.
May 3–June 13,	6	Hay,	1,430	1,410	20—
June 14–July 11,	4	Hay-oat feed,	1,410	1,435	25+
July 12–August 8,	4	Hay,	1,435	1,425	10—
August 9–September 12,	5	Hay-oat feed,	1,425	1,440	15+

Chub.

Dates.	Weeks.	Character of Ration.	Weight, Beginning.	Weight, End.	Gain or Loss.
May 3–June 13,	6	Hay-oat feed,	1,370	1,350	20—
June 14–July 11,	4	Hay,	1,350	1,375	25+
July 12–August 8,	4	Hay-oat feed,	1,375	1,390	15+
August 9–September 12,	5	Hay,	1,390	1,430	40+

General Effect of the Ration.

The animals were weighed weekly, and minor variations were noted. Weights at the beginning and end of the change of ration are here given. The weights indicate that Joe evidently was receiving sufficient food to keep him in equilibrium and to enable him to do his work in a satisfactory way, while Chub was receiving a little more than was necessary. The latter was shorter of leg and chunkier in build, and would be termed an easy keeper. During the first period of six weeks (May 3–June 13) both horses lost a little in weight, due to the work required after a winter of comparative inaction. In the second period of four weeks (June 14–July 11) each horse gained 25 pounds irrespective of the ration, due probably to the less amount of work performed. During the third period of four weeks (July 12–August 8) Joe on the hay ration lost 10 pounds, and Chub on the hay-oat feed ration gained 15 pounds, while in the last period of five weeks both horses gained somewhat, probably because of the less strenuous character of the daily work requirements.

Summary and Discussion.

The term "oat feed" does not refer to ground oat hulls, but to the so-called "mill run" resulting from the first milling of oats. The product from the large modern mills contains some 80 per cent of hulls and 20 per cent of middlings and dust. Because of the finely ground condition of the hulls as placed upon the market it is not possible to separate the hulls from the middlings by mechanical means. An average quality of oat feed contains 5 to 6 per cent of protein, about 2 per cent of fat, and not over 27 per cent of fiber. Less protein and fat and more fiber indicate an excess of hulls, while more protein and fat and less fiber show an extra amount of middlings, and consequently a superior product.

While in digestibility oat feed falls a little below hay, feeding trials with dairy cows have shown it to be slightly superior in the production of milk.

In case of horses, the feeding of 5 to 6 pounds daily of oat feed in place of a like amount of hay was productive of quite satisfactory results, and no disturbances of any kind were noted during the four and a half months of the trial. It may be possible to substitute more than 6 pounds of oat feed for a like amount of hay, but we should hardly advise it, both because of its lack of palatability and its lack of bulk as compared with hay. The feeding of 1 pound of cottonseed meal daily in the grain mixture was in no way injurious, so far as we were able to observe, and it is believed that the extra protein furnished had a favorable effect upon the animals.

The writers are of the opinion that oat feed, if placed upon the market unmixed, can best be used pound for pound as a partial hay substitute for dairy cows, young stock, fattening cattle and horses, providing the supply of hay is limited and oat feed can be bought at a reasonable price.

From 6 to 8 pounds daily can thus be fed (well moistened) to mature bovines, proportionately less to young stock, and about 5 to 6 pounds daily to horses.

While oat feed is used in considerable amounts in many proprietary grain mixtures, the best grades, whether rich in protein or carbohydrates, cannot contain large quantities for the reason that such an addition would unduly increase their fiber content and also lessen their digestibility.

The claim is made that aside from its nutritive value, oat feed possesses merit as bulk, serving to distribute and lighten the heavier concentrates. How valid this claim is has not been proved, although as a result of experience many feeders claim that the feeding of considerable amounts of a grain ration which lacks bulk is not advisable. Be that as it may, the use of a few hundred pounds (about 15 per cent) of oat feed in a ton of home-mixed ration would not be objectionable, especially if the other ingredients are highly digestible and finely ground.

In view of the ever-increasing demand for the grains as human food, it should be the aim of both the manufacturer and feeder to use the by-products to the best advantage. Methods for improving the digestibility of indigestible materials, such as grain hulls and the like, merit the careful attention of investigators.

Oat feed should bear a guarantee of composition, and the manufacturers should be careful that it is of stable composition. The purchaser will lose confidence if it shows variations from an accepted standard, or if material is offered as oat feed which consists only of ground oat hulls.

Low-grade by-products, of which oat feed is a type, must be *sold on their merits* and at a price commensurate with their feeding value. Any attempt to sell such material either by itself or in proprietary mixtures at prices unwarranted by its feeding value as compared with feeding stuffs of higher grade would quickly destroy the confidence of the purchaser and result in a slackened demand for the article. The old motto of "state what you sell and sell what you state" may be improved by the addition of the clause "at a price commensurate with its value," and would be especially applicable to this class of materials.

INDEX

INDEX.

PUBLIC DOCUMENT No. 31

MASSACHUSETTS AGRICULTURAL COLLEGE

THIRTY-FOURTH ANNUAL REPORT OF THE MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

PARTS I AND II

1921

Publication of this Document
approved by the
Supervisor of Administration.

THIRTY-FOURTH ANNUAL REPORT

OF THE

MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

PART I

REPORT OF THE DIRECTOR AND OTHER OFFICERS

PART II

DETAILED REPORT OF THE EXPERIMENT STATION

BEING PARTS III AND IV OF THE FIFTY-NINTH ANNUAL REPORT OF THE MASSACHUSETTS AGRICULTURAL COLLEGE

A RECORD OF THE THIRTY-NINTH YEAR FROM THE FOUNDING OF THE STATE AGRICULTURAL EXPERIMENT STATION

CONTENTS.

Part I.

Part II.

Massachusetts Agricultural Experiment Station.

OFFICERS AND STAFF.

COMMITTEE.

STATION STAFF.

Administration.

Sidney B. Haskell, B.Sc., *Director*.
Joseph B. Lindsey, Ph.D., *Vice-Director*.
Fred C. Kenney, *Treasurer*.
Henry S. Green, A.B., LL.D., *Librarian*.
Mrs. Lucia G. Church, *Secretary to the Director*.
Miss F. Ethel Felton, A.B., *Clerk and Editorial Assistant*.

Agricultural Economics.

Alexander E. Cance, Ph.D., *Professor*.
Miss Lorian P. Jefferson, M.A., *Assistant Research Professor*.

Agriculture.

Edwin F. Gaskill, B.Sc., *Assistant Research Professor*.
Robert L. Coffin, *Investigator*.

Botany.

A. Vincent Osmun, M.Sc., *Professor*.
Paul J. Anderson, Ph.D., *Professor*.
Orton L. Clark, B.Sc., *Assistant Professor*.
Webster S. Krout, M.A., *Assistant Research Professor*.
Miss Anna M. Wallace, M.A., *Curator*.
Miss Gladys I. Miner, *Stenographer*.
Alyn S. Ball, *Laboratory Assistant*.

Cranberry Station.

Henry J. Franklin, Ph.D., *Research Professor in Charge*.

Entomology.

Henry T. Fernald, Ph.D., *Professor*.
Arthur I. Bourne, A.B., *Assistant Research Professor*.
Harlan N. Worthley, B.Sc., *Investigator*.
Miss Bridie E. O'Donnell, *Stenographer*.

Horticultural Manufactures.

Walter W. Chenoweth, M.Sc., *Professor*.

Market Gardening and Market-Garden Field Station.

Harold F. Tompson, B.Sc., *In Charge, Market-Garden Field Station*.

Meteorology.	JOHN E. OSTRANDER, A.M., C.E., *Meteorologist.*
Microbiology.	CHARLES E. MARSHALL, Ph.D., *Professor.* ARAO ITANO, Ph.D., *Assistant Professor.*
Plant and Animal Chemistry.	JOSEPH B. LINDSEY, Ph.D., *Chemist.* EDWARD B. HOLLAND, Ph.D., *Research Professor.* FRED W. MORSE, M.Sc., *Research Professor.* CARLTON P. JONES, M.Sc., *Assistant Research Professor.* CARLOS L. BEALS, M.Sc., *Assistant Research Professor.* [1] JOHN G. ARCHIBALD, B.Sc.Agr., *Assistant Research Professor.* [2] CHARLES O. DUNBAR, B.Sc., *Investigator.* HARRY L. ALLEN, *Laboratory Assistant.* JAMES R. ALCOCK, *Assistant in Animal Nutrition.* Miss MARGARET C. EPPLER, *Clerk.*
Pomology.	FRED C. SEARS, M.Sc., *Professor.* JACOB K. SHAW, Ph.D., *Research Professor.* ARTHUR P. FRENCH, B.Sc., *Investigator.* Miss ETHELYN STREETER, *Stenographer.*
Poultry Husbandry.	JOHN C. GRAHAM, B.Sc., *Professor.* HUBERT D. GOODALE, Ph.D., *Research Professor.* Miss RUBY SANBORN, A.B., *Clerk.* Miss DORIS TOWER, *Stenographer.*
Veterinary Science.	JAMES B. PAIGE, B.Sc., D.V.S., *Professor.* [1] G. EDWARD GAGE, Ph.D., *Professor of Animal Pathology, Acting Head of Department.* JOHN B. LENTZ, V.M.D., *Assistant Research Professor.*

CONTROL SERVICE.

Miss ETHEL M. BRADLEY, B.Sc., *Analyst, Feed Control.*
RAY A. CARTER, *Collector of Blood Samples, Poultry Disease Elimination.*
OLIVER S. FLINT, B.Sc., *Analyst, Poultry Disease Elimination.*
HENRI D. HASKINS, B.Sc., *Official Chemist, Fertilizer Control.*
JAMES T. HOWARD, *Inspector, Feed and Fertilizer Control.*
ANN SMITH, *Analyst, Poultry Disease Elimination.*
PHILIP H. SMITH, M.Sc., *Official Chemist, Feed Control.*
RAYMOND W. SWIFT, B.Sc., *Analyst, Fertilizer Control.*
LEWELL S. WALKER, B.Sc., *Assistant Official Chemist, Fertilizer Control.*
Miss CORA B. GROVER, *Stenographer, Control Service.*

---

[1] On leave. [2] Temporary appointment.

REPORT OF THE DIRECTOR.

SIDNEY B. HASKELL.

REVIEW OF THE YEAR.

The year just past has seen the completion of reorganization of station work on a project basis. There have been a number of difficulties in attaining this end, among them being the fact of many long-continued pieces of work, started in some cases nearly thirty years ago, which were not adapted to present methods of project organization. Through committee service, however, all such projects have now been subjected to strict analysis. Some of the older projects have been reorganized; others have been brought to completion and await only suitable time for publication. In making report on the present project organization of the station, it seems best to ignore departmental organization save in a minor way, and to classify on the basis of service expected of the projects.

Utilization of Station Work.

A most encouraging development of the year has been the increased utilization of station work in several lines of agricultural endeavor. As concrete illustration, the organization by the Massachusetts Fruit Growers' Association of a nursery certification plan, whereby damage and loss arising from the old difficulty of orchard stock being found untrue to name may be obviated, is a direct result of an investigation started some eight years ago by Dr. Shaw of the Department of Pomology. The work of the Department of Botany has likewise found immediate application in at least two different directions, — first, in giving to the tobacco growers of the Connecticut valley a method whereby "tobacco wildfire," a disease comparatively new in this section, may be controlled by spraying of the seed-bed; and secondly, the demonstration, through the

excellent work done in the eastern part of the State, in co-operation with the Nashoba Fruit Growers' Association and several of the county farm bureaus, that the apple scab, a disease which caused very serious financial loss in 1920, can be controlled. The bringing together in bulletin form of available information on the composition, nature and properties of insecticides and fungicides, through the Departments of Chemistry, Entomology and Botany, is a service to fruit growers and general farmers for which they seem to be most appreciative. The work done in the Department of Plant and Animal Chemistry in studying the possibility of successful preservation of apple pomace promises to bring into general use a home-produced by-product of manufacturing which has heretofore been largely wasted. The work done in the same department and in the Department of Agriculture, extending back for a period of years, on the effectiveness of ammonium sulfate is also very timely, in view of the greatly increased national production of this commodity. Space will not permit of more detailed illustrations.

Changes in Staff.

There have been six resignations during the year; one partial transfer of a station worker to the teaching department of the institution; one staff officer retired through the automatic provisions of the retirement law; and four appointments to new positions. In detail these changes are as follows: —

Miss Anne C. Messer, investigator in chemistry, resigned Jan. 31, 1921, on account of ill health, after a little more than a year of efficient service. The position has been filled by the appointment of Mr. Charles O. Dunbar, a recent graduate of the College.

Miss Rebecca L. Mellor, clerk in the Department of Plant and Animal Chemistry, resigned July 13, 1921. Miss Mellor had given very satisfactory service for a period of seven and one-half years. Miss Margaret Eppler has been appointed in her place.

Miss Marguerite G. Ickis, curator in botany, resigned her position July 31, 1921. Among other items of service to the station and institution particularly noteworthy is the excellence of her photographic work on difficult subjects. This work has

added value to the publications of her department, and will continue to add value as her work is published in years to come. Miss Anna M. Wallace of Smith College has been appointed curator.

Mr. Charles R. Green resigned as station librarian in August. For thirteen years Mr. Green has served in the dual position of librarian for the College and for the Experiment Station. His zeal in the building up of a real scientific library was unflagging. His never-failing courtesy in helping our men to obtain literature on various subjects made his services greatly appreciated and his loss to the station staff all the more keenly felt. Dr. Henry S. Green has been appointed librarian.

On Aug. 10, 1921, Dr. George H. Chapman, who had been in the service of the institution since 1907, resigned his position as research professor of botany to take up research work with the newly organized Connecticut Valley Tobacco Improvement Association. Dr. Chapman's loss is much to be regretted. He has had wide experience in his subject-matter, and particularly as a specialist on certain problems connected with the production of tobacco. He had several times visited the tobacco sections of Porto Rico as expert in the employ of large tobacco companies, and in this and other ways had fitted himself to render expert service to this relatively important Massachusetts industry. Despite the loss to the institution incurred by his resignation, it is gratifying to know that Dr. Chapman will continue in research work, although under different auspices. The position has not been filled.

Under date of Jan. 21, 1921, Mr. C. L. Beals, assistant research professor of chemistry, asked for a year's leave of absence without pay, in order to enter upon research work in preservation of milk by-products for the Sheffield Farms Company of Hobart, New York. Toward the end of the year Mr. Beals signified his intention of resigning, thus withdrawing permanently from the work of the station. It is with regret that we have felt obliged to recommend that the resignation be accepted, for Mr. Beals had shown great promise as an investigator. Here again, however, the apprenticeship served by Mr. Beals in the station has fitted him for an important research position, — a position in which success will ultimately react to the benefit of dairy farmers the country over. The

position has been filled by Mr. John G. Archibald, a graduate of the Agricultural College at Guelph, Ontario.

As of June 1, 1921, Dr. J. B. Lentz was transferred from full time in Experiment Station service to half-time instructional work and half-time station work. This transfer was made necessary by the illness of Dr. James B. Paige, head of the Department of Veterinary Science.

On November 20 Dr. William P. Brooks, formerly director of the Experiment Station, and for nearly thirty years agriculturist of the station, but more recently consulting agriculturist, was placed on full retirement by the State Board of Retirement, having reached the age of seventy years. Dr. Brooks was best known because of the technical and scientific work done during the time over which he was agriculturist of the station. He imported to this country the first trial lot of Japanese millet, a crop which has made a place for itself on nearly all dairy farms in the northeastern part of the country. He also was instrumental in importation and early trials of the Japanese soy bean, a crop which has become important in many sections, but which, as it happens, has not yet established itself in the North. Dr. Brooks also was an acknowledged expert on fertilizer use, and during his many years with the station developed this branch of the work to a very great degree. It is with gratification that we report that, despite automatic retirement under the above-mentioned law, his services will still be available to the station in a consulting capacity.

Mr. Arthur P. French of Ohio State University was appointed investigator in pomology and began work in July.

The poultry disease elimination work was reorganized in September, with the following appointments: Oliver S. Flint, specialist in charge; Miss Ann Smith, laboratory assistant; and Ray A. Carter, collector of blood samples.

Changes in Equipment Organization.

During the year the Harlow farm, so called, was added to the land equipment of the Experiment Station. This area has been under the supervision of the Department of Pomology, and the transfer represents nothing more than an attempt to maintain existing educational values on this tract and add to

them certain research values. The total area is in the neighborhood of thirty acres, about one-half of which is already planted and brought under definitely organized projects. The remaining area must be underdrained before it can be effectively used. A project for this purpose has already been submitted. Once this is done, the land so improved will be available for experiments with small fruits, blueberries, and possibly other native fruits.

In the summer of 1920 definite decision was reached to the effect that the Tillson farm should be developed as an experimental poultry farm. Projects were submitted for the equipment of this farm so as to admit of permanent housing of station flocks, and to avoid the danger of disease contamination which comes from housing them on a part of the institutional grounds frequently visited by poultrymen from all over the State. Since money was not appropriated for this purpose, the Department of Poultry Husbandry is still laboring under a severe handicap. Some progress has been made, however, in the development of the farm for the purpose in question. The rough pasture land not suited for tillage purposes is being developed for range purposes, the other area utilized for the time being in several pieces of miscellaneous experimental work.

Publications of the Year.

Annual Report.

Thirty-third annual report:

Part I. Report of the Director and Other Officers; 60 pages.

Part II. Detailed Report of the Experiment Station; 136 pages (Bulletins Nos. 195–200).

Combined Contents and Index, Parts I and II; 16 pages.

Bulletins.

No. 201. Insecticides and Fungicides for Farm and Orchard Crops in Massachusetts, by E. B. Holland, A. I. Bourne and P. J. Anderson; 38 pages.

No. 202. Rust of Antirrhinum, by William L. Doran; 28 pages.

No. 203. Tobacco Wildfire: Preliminary Report of Investigations, by G. H. Chapman and P. J. Anderson; 16 pages.

No. 204. Thirty Years' Experience with Sulfate of Ammonia, by F. W. Morse; 16 pages.

No. 205. The Nutritive Value of Cattle Feeds. 3. Dried Apple Pomace for Farm Stock, by J. B. Lindsey, C. L. Beals and J. G. Archibald; 14 pages.

No. 206. Eighth Report of the Cranberry Station, by H. J. Franklin; 20 pages.

Bulletins, Technical Series.

No. 4. Development and Pathogenesis of the Onion Smut Fungus, by P. J. Anderson; 36 pages.

Bulletins, Popular Edition.

No. 201. Insecticides and Fungicides for Farm and Orchard Crops in Massachusetts, by E. B. Holland, A. I. Bourne and P. J. Anderson; 16 pages.

Bulletins, Control Series.

No. 15. Inspection of Commercial Feedstuffs, by Philip H. Smith and Ethel M. Bradley; 34 pages.

No. 16. Inspection of Commercial Fertilizers, by H. D. Haskins, L. S. Walker and R. W. Swift; 40 pages.

No. 17. Inspection of Lime Products Used in Agriculture, by H. D. Haskins, L. S. Walker and R. W. Swift; 8 pages.

Meteorological Reports.

Nos. 385–396, inclusive, 4 pages each.

REPORT ON PROJECTS.

Plant Nutrition.

CHEMICAL INVESTIGATIONS.

Department of Plant and Animal Chemistry.

Project 6. "Lime absorption and acidity of Field A."

Professor MORSE and Assistant Professor JONES.

This study of the application of fundamental laws affecting solubility in the soil solution has led to important results which are now being prepared for publication. Following this it is expected that a chemical study will be made of the reaction between nitrate of soda, muriate of potash and lime as manifested by the composition of the drainage water.

Project 7. "Effect of sulfate and muriate of potash on the soils of Fields A and B."

Professor MORSE and Assistant Professor JONES.

Work on this project is being carried on in connection with that of the one immediately preceding.

Project 14. "A study of the availability of soil potash, with the object of developing a system of diagnosis for soils of the State."

Professor MORSE and Assistant Professor JONES.

This work supplements that carried on some years back by former Director Brooks in the investigation of subsoil potash, and during this past year was confined to an attempt at measuring the effect of moisture on the availability of soil potash.

MICROBIOLOGICAL INVESTIGATIONS.

Department of Microbiology.

Project 2. "Soil fertility as influenced by micro-organisms in their relation to the presence and disappearance of organic matter."

Assistant Professor ITANO and Mr. SANBORN.

Particular attention has been given to the activities of *Azotobacter* and *Bacillus radicicola* in their relation to those

organic matters which are known as "growth accessory substances." An electrometric method for the determination of carbon dioxide, which was developed last year, has been employed in the investigation. The results of the investigation, together with the method used, will be ready for publication in the near future. There has also been a study made of the microbial decomposition of cellulose.

PHYSIOLOGICAL INVESTIGATIONS.

Department of Botany.

Project 1. "Optimum conditions of light for plant response."
Assistant Professor CLARK.

This project was started in 1915 under the Adams fund. At present the work is divided into two parts: "A study of the light requirements of field and garden crops," and "Study of the effect of ultra-violet light on plant growth." The investigation is carried on both in the greenhouse and out of doors, and by natural as well as by artificial light.

Project 15. "Plant stimulation by formaldehyde."

Owing to Dr. Chapman's resignation from the station staff, no work has as yet been done on this project.

Department of Pomology.

Project 1. "Study of the interrelation of stock and scion in apples."

Professor SHAW.

This project was begun in 1912, and the main orchard set in 1915 and 1916. A new orchard of 450 trees was set in the spring of 1921 from the surplus trees on known roots in the nurseries, in which it is planned to investigate the nature of the graft union between certain varieties. In resetting these trees the relation of crown gall to different varieties was studied and data collected showing that each root variety exhibits a special form of the gall, and that some varieties are highly resistant to the disease. No reports on this project have as yet been published.

Project 12. "Apple variety fruit spur study."
Professor SHAW and Assistant Professor DRAIN.

This project comprises a detailed study of individual fruit spurs, in an endeavor to define the service and functions of pruning and fertilizing in modifying fruit-bud formation and fruit production. The field work is checked by chemical study of the elaboration of food in the fruit spur, and by micro-chemical tests.

Project 14. "Winter injury of brambles."
Professor SHAW, Professor MORSE and
Assistant Professor CLARK.

This project, co-operative between the Departments of Botany, Chemistry and Pomology, was organized to investigate the cause of the winterkilling of brambles as apparently brought about by differential fertilization with potash salts. This winterkilling was observed again and again on some of the plot work initiated by Dr. Goessmann years back, but was never satisfactorily explained. In an attempt to solve this problem both chemical and physiological tools are being used.

SOIL MANAGEMENT AND FERTILIZER TESTS.

Department of Agriculture.

Project 1. "Comparison of nitrogenous fertilizers."
Professor MORSE and Assistant Professor GASKILL.

This investigation is co-operative with the Department of Plant and Animal Chemistry. While the experiment was originally instituted to study the relative value of different sources of fertilizer nitrogen, the greatest contributions have been incidental to what was considered the main objective. The possibility of maintaining yields almost indefinitely without the use of fertilizer nitrogen has been demonstrated. Certain problems of soil acidity have been studied, and the presence in acid soils of certain toxic substances experimentally proved. The latest contribution from this field was in the publication of Bulletin No. 204, entitled "Thirty Years' Experience with Sulfate of Ammonia."

Project 3. "Residual value of excess phosphate applications."

Assistant Professor GASKILL.

In this project attempt is being made to utilize reserves of phosphoric acid built up in the soil from past fertilizer treatment. One of the older station plots, having an unbroken history of twenty-five years, is now being used for this work. The experiment as changed is now in its second year, and hence has not given definite results.

Project 4. "Methods of applying lime, and quantity of application."

Assistant Professor GASKILL.

In preparing land for future alfalfa crops, lime has been applied in varying rates, plowed under, harrowed into the surface, and both plowed under and harrowed in. The plots are repeated in quintuplicate.

Project 6. "Top-dressing permanent grasslands."

Assistant Professor GASKILL.

Certain areas of land formerly used for experimental work, but which were in old sod at the beginning of the experiment, are being used in this test. The fertilizer applications are purposely kept at a low rate. The results of the first year, as might have been expected, emphasize the great importance of nitrogen in producing heavy yields of grasses.

Project 7. "An attempt to restore productive fertility to worn-out and maltreated soils."

Assistant Professor GASKILL.

This project was initiated in the spring of 1921. The plots of the old South Soil Test, which had received differential fertility treatment for over thirty years, and in some cases reached a very low state of productiveness, furnish the basis for the study. The results the first year indicate an astonishingly rapid and marked response to present rational treatments.

Department of Botany.

Project 13. "Ecological study of pasture vegetation."
Professor OSMUN and Director HASKELL.

This project is co-operative with the Department of Agriculture. Its primary object is to determine the effect of chemical fertilizers and lime on natural pasture vegetation, in the hope of making some contribution toward solving the problem of bringing run-down pastures to a state of productivity. In the pasture on the Tillson farm a number of plots of equal area were selected, each dominated by a different type of vegetation characteristic of run-down pastures. These were designated as "moss area," "cinquefoil area," etc., according to the principal plant growths which they embraced. The attempt is being made to determine the specific effect on each dominating type of vegetation of treatment given, and likewise the possibility of enabling clover and the grasses to successfully compete with these types of natural vegetation.

Market-Garden Field Station.

Project 1. "Manure economy tests."
Professor TOMPSON.

Work under this project was started in 1918, in an attempt to solve the serious fertility problems developed through increasing shortage of animal manures. Results to date indicate that the amount of manure as used by market gardeners may be greatly reduced in case the manure is supplemented with chemical fertilizers.

Project 5. "Growth control by means of intercropping."
Professor TOMPSON.

Work under this project represents an attempt to use cover crops, intersown, in controlling the growth of certain vegetables in the same way that cover crops as used in the orchard are supposed to control tree growth. The fertilizer schedule in this work is so arranged as to produce rapid and luxuriant growth during the first part of the season, it being expected that the intercrop will relieve the soil of any surplus as the ripening period approaches. This project was started in the spring of 1921.

Department of Pomology.

Project 5. "Comparison of cultivation and sod mulch in a bearing orchard."

Professor SHAW and Mr. FRENCH.

This project was started in the spring of 1921 on a ten-year-old orchard of Baldwin, McIntosh, Wealthy and Oldenburg, on the Harlow farm. The area is about three acres and is divided into seven plots, three of which are to be seeded to Kentucky blue grass and to receive 300 pounds of nitrate of soda per acre. The other four plots are to be cultivated with a cover crop and are to receive little or no fertilizer.

Project 6. "Comparison of clover and grass in a sod mulch orchard."

Professor SHAW and Mr. FRENCH.

The trees on the area assigned to this project were planted in 1911 and consist of Wagener, Wealthy and Oldenburg. Two of the five plots were seeded to grass in the spring of 1921, and are to receive a complete fertilizer designed to further grass production. On the other three plots the fertilizer application is confined to phosphorus and potassium, with a mixture of white clover and Kentucky blue grass sown. It is hoped by this differential treatment to foster the growth of clovers, and thus make measurement of the effect of grass and applied nitrogen as against the effect on the apple trees of clover plus such nitrogen as it may accumulate from the air. The first effect, as might have been expected, was more marked on the two plots receiving nitrogen.

Project 7. "Test of fertilizers in a sod mulch orchard."

Professor SHAW and Mr. FRENCH.

This orchard was brought under experiment in the spring of 1921, and in area is about two and one-fifth acres. The fertilizer treatments include the following: —

300 pounds nitrate of soda per acre annually.

300 pounds nitrate of soda
300 pounds acid phosphate } per acre annually.

300 pounds nitrate of soda
300 pounds acid phosphate
200 pounds sulfate of potash } per acre annually.

The whole orchard was plowed and harrowed repeatedly last spring in preparation for starting the experiment, which probably accounts for the fact that while fertilizers had a definite effect on the cover crop, none could be observed on the trees themselves.

Project 8. "Test of cover crops for apple orchards."
Professor SHAW and Mr. FRENCH.

The crops used have been red clover, buckwheat, timothy, redtop, weeds, and rape, although the latter crop made but a poor stand. Individual tree records are being taken. No report on this project has as yet been made, and probably none can be made in the near future.

Project 15. "Orchard fertilization."
Professor SHAW and Assistant Professor GASKILL.

This orchard was assigned to the Department of Pomology in the spring of 1921. Previously it has been carried on as an agricultural project, with reports made at more or less frequent intervals in the annual reports of the Experiment Station, the last of these reports being in 1914. All records of this orchard have been summarized, and are now nearly ready for publication. The plan of fertilization was changed this last spring to one supplying approximately equal amounts of nitrogen and phosphoric acid to all the fertilized plots, but carrying on the differential potash treatment as formerly.

Project 16. "Test of different amounts of nitrate of soda."
Professor SHAW and Assistant Professor DRAIN.

This investigation was started in the spring of 1921, utilizing certain areas in the College orchard. Nitrate of soda is applied at the rate of 5, 10 and 15 pounds per tree. Since the effect of the nitrate on fruit production is secured in part through its effect on wood production, it will be several years before the results will be worthy of record.

Crop and Crop Management Studies.

Plant Introduction.

Cranberry Station.

Project 5. "Blueberry investigations."

Professor Franklin.

This project was commenced in 1915, and is co-operative with the Bureau of Plant Industry of the United States Department of Agriculture. About half an acre of sandy soil, underlain with considerable peat, is now planted to this crop. The work includes a test of selected *versus* unselected bushes, as transplanted from adjacent woodlands and swamps; trial of new varieties as produced through the efforts of Mr. Frederick Coville of the United States Department of Agriculture; propagation work; and observation on disease and insect control.

Department of Pomology.

Project 17. "A study of the cultivation of the high bush cranberry."

Professor Shaw.

Two hundred plants of Viburnum were received in the spring of 1921 from the United States Department of Agriculture and set out on the Tuxbury land. These plants are in part seedlings, and in part propagated from cuttings from superior plants.

Strain and Variety Tests.

Department of Agriculture.

Project 5. "Test of meadow fescue *versus* timothy under varying drainage conditions."

Assistant Professor Gaskill and Mr. Coffin.

Work on this project was started in the summer of 1921, with two fairly well-defined moisture conditions in the field, and plots repeated in quadruplicate.

Market-Garden Field Station.

Project 4. "Variety and strain test of tomatoes."

Professor Tompson.

Twenty-five different strains and varieties were under test during the season of 1921, eighteen of these in quadruplicate plots, the balance in simple duplicates. A part of this work was repeated at the home station at Amherst, so as to reduce error due to environment. The most striking indication of the year's work is that differences in yield due to soil conditions are apparently paramount over many of the differences supposedly inherent in the seed itself, and due either to breeding or to the climatic environment in which the seed is produced.

Department of Pomology.

Project 2. "A study of tree characters of fruit varieties."

Professor Shaw and Mr. French.

This project was started in 1912 for the purpose of getting information which would make possible the identification of varieties in the nursery, and which would also serve as a basis for the comparative studies to be made in connection with Project 1, "Study of interrelation of stock and scion in apples." The first report was published in 1914 as Bulletin No. 159, under the title, "The Technical Description of Apples." Photographs of about 100 varieties have been made, and a bulletin discussing the identification of varieties by their leaves is in preparation. So promising has been the progress made that a phase of the work has been taken over by the Massachusetts Fruit Growers' Association, and a plan developed for the certification of certain varieties of apple trees when grown in the nursery row. In the first work done under this plan, 267 out of a total of 2,847 trees were found to be untrue to name, and hence were refused certification. Four hundred and thirty-eight younger trees propagated from trees found untrue to name were also found, making a grand total of 705 trees thus prevented from coming into the hands of practical fruit growers under incorrect names.

To supplement the leaf study work as completed, it is planned to make a study of the winter characters of the bark, wood and buds of apple varieties, in the expectation that these characters may be of further assistance in variety identification, and may render possible the identification of varieties during the dormant season.

Project 13. "Study of varieties of tree fruits."

Professor SHAW and Assistant Professor GOULD.

This is an attempt to collect valuable data by keeping individual tree records of a number of different varieties in the College orchard. It is expected that it will be possible to correlate the performance of different varieties with certain of their growth characters.

BREEDING.

Market-Garden Field Station.

Project 6. "Improvement of Martha Washington asparagus."

Professor TOMPSON.

The yield records in 1,062 individual plants were taken during the season, all of these being of the same strain and supposedly representing a pure line. Wide differences were noted in behavior. A number of plants gave less than five marketable stalks each, while the best plant gave forty-four. Thirty-eight of these forty-four stalks were over half an inch in diameter, which indicates good quality as well as high yield. Another plant gave a crop of seventeen stalks, of which eleven were over one inch in diameter. This study is preliminary to a definite attempt at improvement.

Department of Pomology.

Project 3. "The genetic composition of peaches."

Professor SHAW.

Owing to weather conditions in the spring of 1921, there was no fruit on the breeding orchard this past season. It is impossible, therefore, to make a report of progress at this time.

MANAGEMENT.

Department of Pomology.

Project 4. "Experiments in pruning apples."

Professor SHAW.

These experiments were started in 1916, and compare the following methods of pruning apple trees: globular or vase head, modified leader head, a new form of the true leader head, and unpruned head. Results to date confirm the growing belief that pruning is a dwarfing process, and that heading back is detrimental to fruit-bud formation.

Project 9. "Testing methods of pruning."

Project 10. "Testing of pruning methods on Northern Spy and other varieties."

Professor SHAW.

These are similar to the above in scope. Project 9 is carried out in connection with Project 8, "Test of cover crops for apple orchards."

Crop Protection.

INSECT ENEMIES OF VEGETATION.

Department of Entomology.

Project 2. "Economic importance of digger wasps."

Professor FERNALD.

This project was started in 1909, and represents an attempt to establish the economic importance of the digger wasps and to determine the number and kinds of insects which may be parasitized by them. This project is nearing completion.

Project 3. "Control of the onion maggot."

Assistant Professor BOURNE.

Work on this project has progressed to the point where the possibility of poisoning the onion maggot fly before completion of oviposition has been established. Owing to the seasonal nature of the onion maggot attacks, and to the difficulty of getting comparable results on areas widely separated, it has not yet been possible to organize field test work on an effective scale.

Project 4. "Control of squash vine borer."

Mr. Worthley.

The work of the past year has developed tentative methods for the control of this insect. Such methods are now to be tried out on a field scale.

Project 5. "Control of the squash bug."

Mr. Worthley.

Up to date, results have been negative, in that some of the control measures usually advised have been shown to be worthless under the conditions tried. Positive results have not been secured.

Project 6. "Control of insects in a candy factory."

Professor Fernald and Mr. Worthley.

This work was initiated at the urgent request of a Massachusetts manufacturer who found his product badly infested with certain insects. The problem was that of fumigating to destroy the insect without at the same time injuring the product of the factory. Work is completed and results written up, but not prepared for publication.

Project 7. "Studies of insect outbreaks in various localities."

Professor Fernald.

This project was started a number of years ago, and has been continued through the making of observations year by year. Work this last year was confined to observations on the presence and development of the corn ear worm and seed corn maggot.

Project 8. "Pest limits in Massachusetts."

Professor Fernald.

This project attempts to correlate the presence and development of certain insect pests with geographical and climatic conditions in the various parts of the State. Of necessity, observations must be continued over a long period of years before the results will have authoritative value.

Project 9. "Number of generations of codling moth in Massachusetts as related to advisability of spraying for the second generation."

Assistant Professor BOURNE.

This project consists of observations on the development of second generation codling moths in the different climatic areas of Massachusetts.

Project 10. "Hatching dates for scale insects."

Assistant Professor BOURNE.

This project takes in all of the more important scale insects, and attempts to determine hatching dates as affected by seasonal developments. It is hoped that a service of the project may be the establishment of dates on which spraying for certain of these scale insects may be effectively practiced.

Cranberry Station.

Project 1. "Injurious and beneficial insects affecting the cranberry."

Professor FRANKLIN.

Dusting with lead arsenate as a control for gypsy-moth worms in their early stages was tried on two bogs with satisfactory results. The green spanworm was more prevalent than for many years, destroying the promise of a fine crop on two areas of fifty and twenty-five acres in Rochester, and on an area of two or three acres in Carver. Life history studies on this insect were continued. The brown spanworm practically disappeared as a cranberry pest this past year. The fruit worm was more destructive than for several years. Its hatching date was later than usual. Extensive examinations and counts proved that the common parasite was abundant. Wetting of the cocoons with a solution of sodium cyanide was tried as a possible new method of control.

PLANT DISEASE CONTROL.

Department of Botany.

Project 2. "Tobacco investigations and a study of so-called tobacco sick soils."

Professor CHAPMAN and Professor ANDERSON.

Active work on this project was started through a field survey in the summer of 1916. The year following, fertilizer plots were located on three tobacco farms in the Connecticut valley. With some necessary changes these plots were continued over four years, when the experience gained made it apparent that further progress could be made only on land under the complete control of the station. Experimental work on privately owned land was therefore discontinued, being replaced by experimental work carried on at the Tillson farm. The reorganized project embraces a study of soil reaction as a means of controlling root rots of tobacco; also a study of the effects of soil reaction on the growth and development of the crop.

Project 3. "Investigations of the methods of controlling lettuce drop."

Professor OSMUN and Assistant Professor KROUT.

Although this project was not formally organized until January, 1918, the department had previously conducted many investigations along this line. During the year just past, a paper dealing with the more technical phases of this work was submitted for publication in the Journal of Agricultural Research. The most striking result of the investigation to date is the determination of the fact that lettuce drop may be easily and inexpensively controlled by treating infected soils with a formaldehyde solution. A complete report of the work in bulletin form is in course of preparation.

Project 5. "Experimental spraying for the control of cucumber mildew under glass."

Assistant Professor KROUT.

Because but two serious epidemics of this disease have occurred since the project was started, actual spraying tests have been conducted two seasons only. During the summer

just past greenhouse cucumbers were heavily attacked, with losses ranging from 25 to 60 per cent. The use of 4-6-50 Bordeaux mixture appears to be profitable, even though anything approaching perfect control seems at present unattainable.

Project 6. "Investigation of onion diseases."
Professor OSMUN and Professor ANDERSON.

Work under this project has to date been focussed on onion smut, the most destructive disease of onions in this State. A technical paper, entitled "Development and Pathogenesis of the Onion Smut Fungus," is now in press, to be published as a station bulletin. Very striking results have been obtained through formaldehyde treatment of infected soils. The chief difficulty in the application of this method appears to be mechanical limitations in machinery used for distribution of the formaldehyde.

Project 9. "Investigation of carrot blight."
Assistant Professor KROUT.

The causal organism of this disease has been isolated and studied under culture, work has been done on seed disinfection, and field plots have been sprayed. The work, however, has not progressed far enough to warrant definite conclusions.

Project 10. "Apple disease control investigations."
Assistant Professor KROUT.

This project was presented in February of 1921, in response to an urgent appeal of apple growers in the eastern part of the State for help in controlling apple scab and black rot. Through the co-operation of the Nashoba Fruit Producers' Association and several of the county farm bureaus, transportation facilities, spraying equipment, labor and orchard space were allowed the station for carrying on this work. The value of the season's results was somewhat reduced by late spring frosts which killed a large part of the fruit buds. Indications to date are that proper spraying can control scab in eastern Massachusetts. The best results were obtained on plots where Bordeaux mixture was used for the "pink bud" spray, and liquid lime-sulfur for later applications. Results from dusting were inconclusive. This work should continue at least three years and probably longer.

Project 14. "Investigation on control of tobacco wildfire."
Professor CHAPMAN and Professor ANDERSON.

This project was organized in May, 1921, in response to an emergency brought about by the sudden and general appearance of tobacco wildfire in the seed-beds of the Connecticut valley. Previous reports of its appearance had been limited to field outbreaks at several points in 1919 and 1920. Because of the great importance of this crop in the Connecticut valley, projects of seemingly lesser importance were laid aside in order to meet the emergency. A preliminary report on investigations was published in the fall as station Bulletin No. 203. Work in greenhouse and laboratory was conducted throughout the winter, and will be carried to seed-beds and plots this coming season.

Cranberry Station.

Project 2. "Cranberry disease work."
Professor FRANKLIN.

This project was conducted, as heretofore, in co-operation with the Bureau of Plant Industry of the United States Department of Agriculture. Additional observations were made on the distribution of the "false blossom" disease. Extensive cultural work was done to determine the periods of greatest infection from different putrefactive fungi, and to discover the effect of June flooding on infection. Further tests and observations on the effect of reflooding on the "rose bloom" disease were made. Spraying tests with lead arsenate as a cranberry fungicide were continued extensively.

SPRAY MATERIALS — THEIR NATURE AND USE.

Department of Botany.

Project 12. "Tests of fungicides on potatoes."
Professor OSMUN and Professor ANDERSON.

This work was planned to test the value of various types of commercial fungicides used for spraying potatoes, in comparison with home-mixed Bordeaux, and is co-operative between the Department of Botany, the farm department and the service

organization of the Experiment Station. The complete absence of late blight in the year just past made impossible the measurement of the action of fungicides on this disease. Yield records indicated no appreciable stimulation of growth by the use of Bordeaux.

Department of Plant and Animal Chemistry.

Project 5. "Chemistry of arsenical insecticides."

Professor Holland and Mr. Dunbar.

Despite its name this project has practically become a study of the chemistry of insecticides and fungicides. Work under this project the past year included the preparation of Bulletin No. 201 in co-operation with the Departments of Entomology and Botany; and a large amount of analytical work done in co-operation with these same departments, with the Department of Pomology, and with the State Department of Conservation. Analytical work was done on concentrated lime-sulfur, lime-sulfur paste, dry lime-sulfur, Sulco V–B, Sander's dust, dry lead arsenate and NuRexo. Assistance was also given in fumigation experiments with hydrocyanic acid. Determination of arsenic in the bodies of dead bees was also made to determine the probability of death being caused by this substance.

Project 13. "A new method for the analysis of dry lime-sulfur mixtures."

Assistant Professor Jones.

Work on this project has been carried on at intervals for the past two years. Results are now being prepared in manuscript form, in order that the method may be critically examined as to its accuracy and usefulness.

Department of Entomology.

Project 1. "Studies of causes of burning of foliage by arsenicals."

Professor Fernald and Assistant Professor Bourne.

This project was started in 1908. Work has been completed and manuscript prepared presenting in graphic form the

results of over 1,500 separate observations on spray injury. This will be published as a station bulletin as soon as opportunity allows.

Project 12. "Determination of the best strength of lime-sulfur."

Assistant Professor BOURNE.

Work on this project was commenced in the spring of 1921. Results as yet are purely tentative.

Project 13. "Study of the possible injurious effects of Scalecide on trees."

Assistant Professor BOURNE.

This project requires a study of the cumulative effect of this spray. Work was commenced in the spring of 1921 with application of one dormant spray. Final report cannot be made until the fact of injury, or of no injury, be established.

Department of Pomology.

Project 11. "To test new spray materials as they become commercially important."

Professor SEARS and Assistant Professor GOULD.

This project was co-operative between the Department of Pomology and the Departments of Botany, Entomology and Plant and Animal Chemistry. The following materials were tested in 1921: —

Sulco V. B. (1920 and 1921 material).
Grasselli Lime Sulfur paste.
NuRexo Bordeaux powder.

These were tried in comparison with dry lime-sulfur and liquid lime-sulfur. All were used with arsenate of lead. The bud pink and calyx sprays were applied to several varieties, including Baldwins and McIntosh. All sprays, even the arsenate of lead alone, caused some burning of the foliage, but this was most serious where Sulco V. B. was used. The lime-sulfur paste was in poor mechanical condition, and there was considerable injury from the Bordeaux powder.

Annual Nutrition.

Animal Metabolism.

Department of Plant and Animal Chemistry.

Project 1. "A study of the chemistry of butter fat and the effect of food in modifying its chemical and physical character."

Professor Holland, Assistant Professor Archibald and Mr. Dunbar.

An exhaustive report has been prepared for publication on the studies relative to the influence of breed, period of lactation, and of the different oils and fats in the ration fed, on the composition of the resulting butter fat. This report includes: (1) composition of butter fat from mixed herd milk, grade Holsteins and grade Jerseys, on normal rations; (2) composition of butter fat from the milk of single animals, grade Holsteins and grade Jerseys, relatively fresh in lactation, on normal rations; (3) composition of butter fat from the milk of single animals of breeds stated, fresh, intermediate, and late in lactation, on a normal ration; (4) composition of butter fat from mixed milk, grade Holsteins, on a normal ration and with the addition of different oils and fats; (5) summary of data, together with such general deductions as seem warranted.

Digestibility of Feeding Stuffs.

Department of Plant and Animal Chemistry.

Project 2. "Digestion experiments."

Professor Lindsey and Assistant Professor Archibald.

The only investigation made under this definite project for the last calendar year was with feterita, a member of the milo maize group. Digestion work was carried on, however, under Projects 11 and 12 of this department.

Project 9. "Determining the digestibility and metabolizable energy in feeds for horses."

Professor Lindsey and Assistant Professor Archibald.

Work on this project has been completed, and the data obtained will shortly be assembled in manuscript form.

Project 11. "Determination of the chemical composition, digestibility and feeding value of kiln dried apple pomace."

Professor LINDSEY and Assistant Professor ARCHIBALD.

This project has been completed and results published as Bulletin No. 205 of the Experiment Station.

Project 12. "Attempting to improve the nutritive value of grain hulls."

Professor LINDSEY and Assistant Professor ARCHIBALD.

There has been considerable activity on this project. Data concerning the effect of chemical treatment on oat hulls and rice hulls have been obtained. It is expected to do further work with cottonseed hulls, barley hulls and flax shives. In view of the large amount of these products now produced in the milling industry of the country, and the extent to which such products are used in Massachusetts agriculture, the economic significance of the project is apparent.

ANIMAL FEEDING.

Department of Plant and Animal Chemistry.

Project 10. "Experiments in feeding pigs."

Professor LINDSEY and Assistant Professor ARCHIBALD.

Work on this project was confined to the taking of records on feeding of different amounts of semi-solid and dried buttermilk. Results indicate these materials to be uneconomical when used for pork production.

Project 16. "Vitamines as aids in the production of growth in pigs."

Professor LINDSEY.

This investigation was undertaken the past season in cooperation with the Department of Animal Husbandry. The work was under the immediate oversight of a graduate student, with expectation that it would form a part of a thesis for advanced degree. The use of green feed, either because of its

service as a vitamine carrier, or for other reasons, improved growth. Corn germ meals were found unsatisfactory as carriers of vitamines.

Miscellaneous.

Department of Plant and Animal Chemistry.

Project 3. "Summer forage crops."

Professor Lindsey.

Work the past season was confined to the growing of corn and soy beans, alone and in combination, at different planting rates, and by different planting methods. The past history of the land used in the experiment, however, was such as to render impossible the drawing of definite deductions from this work.

Project 4. "Record of the station herd."

Professor Lindsey.

This is a continuing project in which accurate record is kept of the food consumed by individual cows, the amount of milk produced, the determination of milk solids and milk fat, and estimation of the food costs. As records accumulate this work is of increasing value.

Studies of Heredity in Poultry.

Department of Poultry Husbandry.

Project 1. "Broodiness in poultry."

Professor Goodale.

The line of attack includes the following: (1) Elimination of broodiness from the high lines through suitably tested matings. The percentage of broodiness has now been reduced to about forty. One family of eleven daughters has been produced apparently entirely free from broodiness, and another and highly inbred family shows but one broody member out of fourteen daughters. (2) Production of intensely broody race. (3) Investigation of the effect of crossing. This work is supplemented by physiological studies of the different organs associated with the phenomenon of broodiness.

Project 2. "To determine the mode of inheritance of various characters of poultry, and to study factors governing form and function."

Professor GOODALE.

The previous project really represents an attack on one phase of this larger problem. In studying the inheritance of fecundity it was found that this character was split up into at least five major elements. Through treating each of these elements as units steady progress is being made in breeding for increased egg production. In addition to the foregoing, considerable work is being done on the study of various factors of inheritance and morphogenesis.

Animal Disease Control.

Department of Veterinary Science.

Project 2. "Methods of diagnosis of bacillary white diarrhea."

Professor GAGE.

This project is being brought to a close, and results and interpretations are being compiled in manuscript form. It is expected that the manuscript will be published as a station bulletin some time during the coming year.

Project 3. "Study and control of poultry diseases in College and station flocks."

Assistant Professor LENTZ.

This represents a record of control measures taken to wipe out disease conditions as occurring in the College poultry flock in the spring and summer of 1920, together with a study of the effectiveness of the methods used.

Project 4. "Study and control of bovine abortion and complications in the College herd."

Assistant Professor LENTZ.

As with the foregoing, this project is largely a record of means taken to meet an outbreak of bovine abortion in the College herd. Records to date indicate a very great decrease in the virulency of the disease.

Human Food.

Department of Microbiology.

Project 1. "Microbiological investigations in milk."
Mr. AVERY and Mr. NEILL.

The past year saw practical completion attend several undertakings bearing upon the presence of Streptococci in milk, and their relation to other Streptococci found in disease. A report on one of these undertakings has been accepted for publication in "Dairy Science." This deals with a study of the groupings of Streptococci known as lactic Streptococci. Another piece of work which is nearly ready for publication consists of the study of these Streptococci in their relation to growth conditions and reducing values upon methylene blue, a reagent which has been employed for a number of years in certain dairy determinations.

Another aspect of this study deals with the proteolytic action of the lactic Streptococci as compared with other Streptococci and their capacity to produce, particularly, amino acids and ammonia.

Project 3. "Canning investigations in the light of normal and resistant organisms in continuous, fractional and pressure methods of sterilization."
Professor MARSHALL and Mr. MCCRIMMON.

Further work on this project was done during the year in the study of the thermal death point in connection with canning. Progress, however, has been delayed through lack of the necessary assistance.

Agricultural Economics.

Department of Agricultural Economics.

Project 1. "Local balance of trade in farm products."
Assistant Professor JEFFERSON.

This project was undertaken with a view to discovering quantities of farm products produced and consumed in several

communities of the State, the quantities shipped out, and the methods of marketing local farm produce. The study was begun in Holyoke some time ago, and this year has been continued in Fitchburg. It is expected that the study will be taken up in at least two other communities during the coming year.

Project 2. "Methods and cost of distribution of tobacco, onions and potatoes."

Professor Cance and Assistant Professor Jefferson.

Work under this project has been continued and records taken on the production and distribution of Connecticut valley onions during the years which have elapsed since the publication of Bulletin No. 169, "The Supply and Distribution of Connecticut Valley Onions." No work has been done during the past year on either tobacco or potatoes.

Meteorological Studies.

Department of Meteorology.

The recording day by day of meteorological phenomena, and the publishing of monthly summaries for distribution to parties interested has been continued. The year just closed was the thirty-third over which this work has continued. When combined with the records taken by the late Professor Snell, the station has an unbroken meteorological record of eighty-six years. Work of this kind becomes more and more valuable as such records accumulate.

Department of Entomology.

Project 11. "Study of area of the late frosts as shown by insect distribution."

Professor Fernald.

This is a continuing project, which aims to establish the correlation of certain late frost areas in the State with the presence or absence of certain insects. Little work was done this past year on account of lack of opportunity.

Cranberry Station.

Project 3. "Weather observations with reference to frost prediction."

Professor FRANKLIN.

As in past years, the United States Weather Bureau has telegraphed daily reports from the district forecaster in Boston. Further study has been made as to correlation of certain meteorological conditions and frost probability. Through the co-operation of cranberry growers, and under financial support from their association, frost warnings are now being sent out whenever conditions necessitate.

CONTROL AND REGULATIVE WORK.

By State law, the enforcement of four different control or regulative laws is vested in the Experiment Station. These are the fertilizer control, provided for under sections 250 to 261 of chapter 94 of the Revised Laws of Massachusetts; the feed control, provided for under sections 225 to 235 of the same chapter; the poultry disease elimination, provision for which is found in sections 17 and 21 of chapter 75 of the same laws; and the inspection of dairy glassware and examination of milk testers, provided for in sections 25 to 31 of chapter 94.

The immediate responsibility for the execution of all of the above laws is vested in the Department of Plant and Animal Chemistry, with the exception of the poultry disease elimination law, for which the Department of Veterinary Science is the controlling agency. Detailed reports of operations under these various control laws follow.

Fertilizer Control.

H. D. Haskins, Chemist in Charge,

L. S. Walker, Assistant Chemist, R. W. Swift, Analyst.

During the season of 1921, 109 manufacturers, importers and dealers have secured certificates for the sale of 548 brands of fertilizer and fertilizing materials and 31 lime compounds. The following statistics have been gathered with reference to the year's inspection: 10,567 tons of fertilizer and fertilizing materials were inspected, necessitating the sampling of 21,859 sacks; 199 towns were visited; 1,504 samples, representing 556 distinct brands, were drawn from stock found in the possession of 546 agents or owners; 302 agents were called upon who had discontinued handling fertilizer; 783 analyses were made. In case of lime compounds, 1,106 tons were inspected, necessitating the sampling of 1,194 sacks; 39 towns were visited; 49 samples, representing 27 distinct brands, were drawn from stock found in the possession of 48 agents or owners; 28 analyses were made.

The following table shows the number of brands of the different materials which were registered and sampled, as well as the number of analyses made: —

Materials.	Brands registered.	Brands sampled.	Analyses made.
Complete fertilizers	300	287	308
Ammoniated superphosphates	49	38	43
Superphosphates with potash	7	6	7
Ground bone, tankage and dry ground fish	55	50	70
Nitrogen compounds	77	63	223
Phosphoric acid compounds	32	30	33
Potash compounds	16	14	19
Wood ashes	3	3	29
Pulverized animal manures	11	9	23
Lime compounds	31	27	28
Totals	581	527	783

Full details of the fertilizer inspection work may be found in Bulletin No. 16, Control Series, published in November, 1921; and of the lime inspection work, in Bulletin No. 17, Control Series, published in December, 1921.

Fertilizer Grades and Tonnage sold in Massachusetts from Jan. 1 to July 1, 1921.

From Jan. 1 to July 1, 1921, there were 54,370 tons of commereial fertilizer and fertilizing materials sold in Massachusetts, divided as follows: —

	Tons.
Mixed fertilizers	37,579
Unmixed fertilizing materials	15,073
Pulverized natural manures	1,718

The grades and tonnage of the mixed fertilizers are shown in the following tables, which are arranged to show in the order of their largest tonnage the various grades of (1) high and low analysis complete fertilizers, (2) high and low analysis ammoniated superphosphates and superphosphates with potash, and (3) unmixed fertilizer materials: —

TABLE 1. — *Complete Fertilizers.*

High Analysis (14 Per Cent or over of Available Plant Food).			Low Analysis (less than 14 Per Cent of Available Plant Food).		
Grade.	Tonnage.	Brands.[1]	Grade.	Tonnage.	Brands.[1]
4-8-4	9,484	38	2-8-3	3,261	23
3-8-4	5,915	27	2-8-2	2,726	35
3-9-2	1,527	8	1-8-2	890	9
3-8-3	1,075	9	5-4-4	707	-
4-8-6	1,016	15	5-4-3	522	11
5-4-5	737	12	1-10-1	252	5
6-6-4	606	8	4-4-4	213	-
3-10-3	540	5	1-7-1	184	-
5-8-7	489	8	3-8-2	126	-
3-8-6	485	5	6-4-3	112	-
2-10-4	437	-	3-6-4	87	-
6-12-6	293	-	5-6-1	85	-
4-7-5	285	-	3-6-3	61	-
5-8-4	260	-	4-7-2	58	-
6-8-4	229	-	2-8-1	42	-
6-6-6	218	-	1.22-3-1	33	-
5-8-5	216	5	1.22-3-2	33	-
10-3-4	198	-	1.22-3-3	33	-
4-8-7	171	6	Miscellaneous	120	
5-8-6	166	-			
5-9-4	130	-			
2-8-4	119	-			
7-12-6	107	-			
7-4-4	104	-			
6-4-4	66	-			
2-8-5	64	-			
5-6-5	61	-			
10-8-8	38	-			
6-4-15	37	-			
5-7-2	36	-			
5-6-3	35	-			
5-6-4	25	-			
5-5-4	24	-			
5-4-15	19	-			
3-12-3	17	-			
Miscellaneous	233				
Total . .	25,462	-	Total . .	9,545	-

[1] Where less than five brands of a given grade are registered, the number is not given in this table.

TABLE 2. — *Ammoniated Superphosphates and Superphosphates with Potash.*

High Analysis (14 Per Cent or over of Available Plant Food).			Low Analysis (less than 14 Per Cent of Available Plant Food).		
Grade.	Tonnage.	Brands.[1]	Grade.	Tonnage.	Brands.[1]
4-10-0	307	11	5-4-0	645	-
0-4-15	133	-	3-10-0	365	-
0-12-2	79	-	7-6-0	264	-
0-10-4	73	-	4-8-0	134	-
Miscellaneous	19	-	6-4-0	121	-
			5-8-0	107	-
			6-6-0	88	-
			3-9-0	59	-
			10-3-0	54	-
			5-6-0	44	-
			2-8-0	29	-
			4-3-0	15	-
			Miscellaneous	36	
Totals .	611	-	Total .	1,961	-

TABLE 3. — *Unmixed Fertilizing Materials.*

Material.	Tonnage.	Brands.[1]
Cottonseed meal	6,033	37
Acid phosphate	3,385	29
Nitrate of soda	1,875	25
Pulverized natural manures	1,718	11
Ground bone	860	28
Wood ashes	691	-
Dry ground fish	661	14
Ground tankage	535	19
Sulfate of ammonia	442	10
Sulfate of potash	176	6
Muriate of potash	170	8
Castor pomace	66	-
Nitrate of potash	62	-
Raw ground phosphate	48	-
Precipitated bone	39	-
Kainit	25	-
Dried blood	5	-
Totals	16,791	-

[1] Where less than five brands of a given grade are registered, the number is not given in this table.

An analysis of the foregoing tables reveals the following facts: —

1. Sixty-nine per cent of the total tonnage sold was made up of mixed goods, and 31 per cent of chemicals and unmixed fertilizer by-products.

2. Of the 37,579 tons of mixed goods sold, 93 per cent were complete fertilizers and 7 per cent were ammoniated superphosphates and superphosphates with potash.

3. Of the 35,007 tons of mixed complete fertilizers, about 73 per cent were high analysis (14 per cent or over of available plant food) and 27 per cent low analysis fertilizers (less than 14 per cent of available plant food).

4. The 25,462 tons of high analysis complete fertilizers were, with the exception of 233 tons, furnished by thirty-five grades of fertilizer, that is, formulas having their plant food present in various proportions. About 88 per cent of the total tonnage of the high analysis mixtures was furnished by eleven grades of fertilizer, and about 79 per cent of the balance was furnished by thirteen other grades; or, expressed in another way over 97 per cent of the total tonnage of high analysis fertilizers was furnished by twenty-four grades.

5. The 9,445 tons of low analysis fertilizers were, with the exception of 120 tons, furnished by eighteen grades of fertilizer, and over 94 per cent of this tonnage was furnished by ten grades of fertilizer.

6. In case of the ammoniated superphosphates, of the 2,278 tons sold, over 86 per cent were low analysis goods. The tonnage of high analysis ammoniated superphosphates was furnished by one grade, and 87 per cent of the tonnage of the low analysis was furnished by seven grades.

7. Thirty-six per cent of the total tonnage of mixed fertilizer was derived from grades recommended for the East by the soil improvement committee of the National Fertilizer Association; and over 64 per cent of the total tonnage deviated by 1 per cent only, in nitrogen, phosphoric acid, or potash, as the case might be, from grades thus recommended.

8. With reference to chemicals and crude stock materials, the distribution of the tonnage was as follows: about 57 per cent of the total tonnage was nitrogen products; about 26

per cent, phosphoric acid products; and about 7 per cent, potash products. In all probability the tonnage of unmixed potash salts is abnormally low on account of the high prices which have prevailed for this ingredient.

With reference to the uneconomic phase of the purchase of low analysis fertilizers, it is estimated that the plant food bought by the Massachusetts farmers in 1921 in form of low analysis fertilizers cost them about $94,000 more than if it had been bought in the form of high analysis mixtures. To this should be added the extra cost of freight, cartage and labor for application to the land.

Feed Control.

P. H. Smith, Chemist in Charge.
Miss E. M. Bradley, Analyst.

During the year, 1,121 samples of feeding stuffs, collected of dealers and manufacturers, were analyzed and are reported in Bulletin No. 15 of the Control Series. Two hundred and twenty-one dealers located in 136 towns were visited at least once. One thousand, three hundred and forty-nine brands of feeding stuffs were registered for sale in Massachusetts by 258 dealers. The purchase of an automobile for the use of the inspector not only enabled him to save much time, but also made it possible to visit more frequently stores not easily accessible on account of their distance from railroad and trolley lines.

In common with other business, the grain trade has been extremely unsettled, and in order to meet a falling market much feed has been sold by the retailer at less than the wholesale price at the time of purchase.

No serious cases of adulteration and misbranding were discovered. While it is true that some feeders may not use the best of judgment in their selection of feeding stuffs offered, the guarantee requirement of the feeding stuffs law including a statement of ingredients, enables the purchaser to determine the quality of the goods he purchases. The law does not prohibit the sale of any material which is not actually injurious, but simply requires that such information be furnished the purchaser, by means of the guarantee, as to enable him to know just what he is buying.

Poultry Disease Elimination Law.

George E. Gage, in Charge.
O. S. Flint, Specialist in Charge.

During the year, 24,718 breeding hens have been tested under the poultry disease elimination law, distributed in Worcester, Middlesex, Norfolk, Essex, Plymouth, Bristol, Hampshire, Hampden, Franklin and Berkshire counties. Of this number, 10,897 were Rhode Island Reds, 3,033 White Rocks, 1,890 Barred Rocks, 5,539 White Leghorns, 974 White Wyandottes, and 2,385 miscellaneous. The infection, as indicated by the agglutination test, has been 12.5 per cent for the total 24,718. Twenty-five flocks were found free from infection. The demand for this testing work is increasing all the time, and in a few years, if funds are available to perfect the epidemiological phases of the problem, great benefits will result. A glance at the United States census report for 1920, under the heading of "Massachusetts Industries," will show that there were by census more than 1,455,000 chickens in the State, the value of poultry products being $10,700,000 per year. It would appear from these figures that the State would be justified in the yearly expenditure of $10,000 to protect and improve such an industry.

The Dairy Law.

P. H. Smith, Chemist in Charge.

The dairy law, so called, requires operators of the Babcock test, where such test is used as a basis of payment for milk or cream, or for the purposes of inspection, to secure a certificate of proficiency from the Experiment Station. Forty-six applicants were given the required examination and received certificates. The act requires, also, that all glassware used by licensed operators be tested for accuracy and so marked. Out of a total of 4,664 pieces of glassware tested only 6 have been condemned. In addition to the preceding, an annual inspection of machines and apparatus is also required. This inspection was carried out by Mr. J. T. Howard, authorized deputy, who visited six creameries, fifty milk depots and thirty-five milk-inspection laboratories. Reinspections on account of repairs

ordered will be necessary at fourteen places. It is of interest to note that, in general, machines were in greater need of repair than for any time in recent years, presumably on account of the present business depression which caused owners to defer making repairs as long as possible. The recent explosion of a machine in a milk plant near Boston, which resulted in serious injury to two men, should serve as a warning to those using machines out of repair.

TESTING OF PURE-BRED COWS FOR ADVANCED REGISTRY.

P. H. SMITH, CHEMIST IN CHARGE.

On account of the ever-increasing amount of advanced registry work, it has become necessary to engage a clerk to aid in general supervision and in the keeping of records. Not less than ten and as many as fifteen men have been employed in making the two-day, monthly tests. For the year ending Dec. 1, 1920, 5,820 two-day tests were reported; for the year just past, 7,250 were reported, — an increase of 1,430 over the previous year. The number of cows on yearly test increased in one year from 519 to 676, the number of farms from 72 to 93.

The number of short-time tests for the Holstein-Fresian Association did not equal the number conducted during the preceding year. Statistics for the Holstein work follow: —

Number of farms visited	30
Supervisors employed	26
Reports turned in:	
60-day	4
30-day	50
14-day	29
7-day	152

Summary of Two-day Test Work, December, 1920, through November, 1921.

Month.	Number of Supervisors, Whole or Part Time.	Number of Cows tested.						Number of Herds visited.					
		Guernsey.	Jersey.	Ayrshire.	Shorthorn.	Holstein.	Totals.	Guernsey.	Jersey.	Ayrshire.	Shorthorn.	Holstein.	Totals.
December	12	192	115	101	28	78	514	37	11	12	3	12	75
January	12	212	119	113	23	72	539	42	12	14	2	14	84
February	15	221	122	103	21	85	552	43	13	13	2	14	85
March	13	223	132	106	20	64	515	43	14	13	2	13	85
April	10	242	132	122	21	78	595	41	14	14	2	12	83
May	13	251	136	140	18	79	627	43	13	14	2	16	88
June	11	256	131	138	21	94	640	46	13	13	2	17	91
July	11	237	135	122	19	109	622	45	14	12	2	15	88
August	11	241	136	120	20	101	618	41	15	12	2	15	85
September	11	248	170	118	18	106	660	37	16	12	2	17	84
October	15	257	147	119	20	119	662	40	16	13	2	19	90
November	15	262	150	133	20	111	676	43	15	14	2	19	93
Totals	-	2,845	1,625	1,435	249	1,096	7,250	-	-	-	-	-	1,031

ANALYTICAL AND DIAGNOSTIC SERVICE.

From the founding of the Experiment Station, work of this character has formed a large part of the service rendered to the people of the State. The work as now organized is carried on in the following departments: —

1. Department of Plant and Animal Chemistry, which has charge of the chemical analytical work.
2. Department of Botany, which performs certain analytical work with reference to seeds, and likewise a large amount of diagnostic work with reference to plant diseases.
3. Department of Entomology, which is subject to numerous calls on the diagnosis of insect troubles.
4. Department of Veterinary Science, which performs similar service with reference to animal diseases, and particularly poultry diseases.

A part of this work has definite investigational value. It is through the information gained in the diagnostic work that the Departments of Botany, Entomology and Veterinary Science are able to keep in touch with conditions all over the State. It must be remembered that the Experiment Station is expected to give State-wide service, but despite this it has no field organization. On the other hand, certain phases of the work are to a certain degree of commercial or personal service nature. This work is being discouraged. Since, however, cost-free service of this kind has been offered by the station for the past forty years, it is not possible to do away with this in any short period of time. The correspondence connected with the carrying on of this service is heavy, and is of a definite extension nature. It is probable that some of this work should be organized under the Extension Service rather than under the Experiment Station.

General Chemical Analytical Service.

DEPARTMENT OF PLANT AND ANIMAL CHEMISTRY,
DR. J. B. LINDSEY, HEAD.

The work for the year ending Nov. 30, 1921, included the following. For comparison, the records of 1919 and 1920 are also included.

Numerical Summary of Laboratory Work.

	1919.	1920.	1921.
Alcohol determinations	–	–	4
Arsenic determinations	3	2	2
Breast milk	1	2	2
Ash analysis of fodder articles	–	–	2
Cider for soluble copper	–	9	–
Coal	–	–	1
Cream	442	378	205
Evaporated milk	1	–	–
Feedstuffs	231	145	196
Fertilizers	157	100	173
Fungicides	–	–	12
Ice cream	–	1	4
Insecticides	7	9	5
Lime products	7	6	9
Lubricating oil	–	–	2
Milk	498	344	587
Semi-solid buttermilk for dissolved metals	–	–	1
Soils for lime absorption capacity and organic matter.	137	137	64
Soils for complete or partial chemical analysis	5	20	15
Tobacco	–	12	–
Urine	–	–	2
Vinegar	7	7	14
Water	60	60	63
Weed eradicator	–	–	1

In connection with experimental work, the following analyses were made: —

	1919.	1920.	1921.
Milk	139	168	200
Feedstuffs	22	114	131
Feces	49	49	43
Urine	25	14	14
Dry matter determinations on pot and plot experiments.	671	288	416
Nitrogen determinations on pot experiments	123	96	60
Phosphoric acid determinations on pot experiments.	12	44	66
Potash determinations on pot experiments	–	48	–
Oven-dried weights	580	–	133

Decrease in certain of the above items, notably that in the number of soil analyses, is due to definite attempt on the part of the station to discourage requests for this kind of service.

Analysis, Germination Tests and Separation of Seeds.

Department of Botany,
Prof. A. V. Osmun, Head.

Germination Tests.

During the year germination tests were made on 448 samples of seeds, as listed below. In nearly all cases the tests were made in duplicate, thus doubling the time, labor and expense involved.

Vegetables.

Beans	4	Endive	3
Beets	2	Lettuce	3
Cabbage	5	Parsley	3
Carrots	33	Pea	1
Cauliflower	1	Radish	4
Celeriac	1	Spinach	33
Celery	14	Tomato	14
Corn, sweet	1	Turnip	4
Dandelion	1		

The 127 samples tested were submitted from 4 cities and towns of the Commonwealth, and 1 from another experiment station.

Field Crops.

Alfalfa	1	Corn	3
Barley	2	Millet	3
Beans, soy	2	Oats	3
Beets, mangel	1	Onions	207
Clover, alsike	2	Rape	1
Clover, red	2	Tobacco	62
Clover, sweet	3	Vetch	1

Of the total of 293 samples tested, 6 were submitted from other experiment stations, 156 from 21 villages, towns and cities of the Commonwealth, and 131 were tested for outside parties but for the benefit of resident growers.

Grasses.

Canada blue	1	Red fescue	4
Creeping bent	1	Redtop	5
Orchard	1	Timothy	1

The samples were received from 4 cities and towns of the Commonwealth, and 4 from other experiment stations.

Miscellaneous.

Balsam fir	2	Pine (White)	5
Hemlock	1	Sage	1
Pine (Austrian)	1	Spruce (Canada White)	1
Pine (Red)	1	Spruce (Norway)	1
Pine (Scotch)	1	Spruce (Wisconsin White)	1

The samples came from 2 towns in the Commonwealth.

Purity Tests.

Of the 41 samples tested, 32 were submitted from 7 cities and towns of the Commonwealth, and 9 from other experiment stations.

Field Crops.

Alfalfa	1	Clover, white	1
Barley	2	Millet	3
Clover, alsike	2	Oats	3
Clover, red	2	Vetch	1
Clover, sweet	3		

Grasses.

Canada blue	1	Orchard	1
Creeping bent	1	Red fescue	4
Mixed grasses for putting greens	10	Redtop	5
		Timothy	1

Tobacco Seed Separation.

Seventy-seven samples of tobacco seed were submitted from 15 towns and villages in the tobacco-growing section of the State.

Diagnostic Service in Animal Pathology.

Department of Veterinary Science,
Dr. G. E. Gage, Acting Head.

During the year, 636 different sets of diseased material were submitted to the departmental laboratories for examination. In most cases these materials were accompanied by letters requesting suggestions for treatment. This has involved the classification and recording of a large amount of correspondence. A large percentage of the materials submitted have been examined bacteriologically, serologically and pathologically. Diagnosis reports and suggestions were made concerning cases of the following diseases: —

Abdominal hemorrhages
Anemias
Antresias
Apoplexy
Ascites
Aspergillosis
Bacillary white diarrhea
Biliary obstructions
Biological atrophy
Cachexia
Calf scours
Caseation necrosis
Cercomoniasis
Chicken-pox
Choleolithiasis
Chronic atrophy
Chronic indigestion
Coccidiosis
Congestion of the lungs
Cutaneous emphysema from ruptured air sacs
Diphtheritic roup
Duck septicæmia
External parasites
Fatty metamorphosis of liver
Fermentative infection of gastro-intestinal tract
Fibromæ
Fowl cholera
Fowl typhoid
Gangrenous dermatitis
Gaseous enteritis
Impaction of crop
Impaction of duodenum and intestines
Infarction of kidney
Infectious necrosis of canaries
Intestinal congestion
Intestinal diarrhea
Intestinal intussusception
Intestinal parasites
Jaundice
Laryngitis
Leukemia
Limber neck
Lung strongylosis of pigs
Multilocular cysts of ovary
Nasal catarrhs
Necrosis of liver
Nephritis
Nodular tæniasis
Occlusion of bile duct
Œdema of prepuce in sheep
Œsophageal obstruction
Ovarian inflammation
Ovarian obstruction
Ovarian tumors
Paralysis
Pericarditis
Peritonitis

Pneumonia
Poisoning
Pressure atrophy
Rachitis
Ruptured oviduct
Sarcoptes mutans and Sarcoptes levis infestation
Septicæmia
Sporadic dysentery in calves
Staphylococcus infections of ovary
Stomach worms in sheep
Streptococcic arthritis
Streptococcic mastitis in cows
Streptococcus infection
Suffocation
Superficial erythema
Superficial ulcers of skin
Thrombosis
Traumatic tumors
Avian tuberculosis
Gizzard ulcers in poultry
Uremia
Uric acid arthritis
Visceral gout

In addition, a large amount of diagnostic service was given to the animals of the College and Experiment Station flocks and herds. The following represents the cases examined for disease during the past year: —

Horses.	Cattle.	Sheep.	Pigs.
Arthritis.	Laceration abomasum.	Dermatitis.	Arthritis.
Bronchitis.	Arthritis.	Dystokia.	Dystokia.
Cartilage infections.	Castration.	Impaction.	
Castration.	Dystokia.	Indigestion.	
Coronitis.	Calf diarrhea.	Mastitis.	
Labial retention cysts.	Erythema.	Pneumonia.	
Float molars.	Eversion of vagina.	Post-mortem examinations.	
Colic.	Eversion uterus.		
Influenza, vaccine administration, all farm horses.	Indigestion.		
Laminitis.	Mastitis.		
Omphalo-phlebitis.	Parturient paresis.		
Pervious urachus.	Pericarditis.		
Pneumonia.	Pododermatitis.		
Strangles.	Ringworm.		
Traumatisms.	Traumatisms.		
Fistulous withers.	Post-mortem examinations.		
Post-mortem examinations.	Subcutaneous tuberculin testing of both herds.		
	Ophthalmic and intradermal check tests.		

The Department of Veterinary Science has manufactured and standardized its own diagnostic sera, twenty-two different types being made in the year in question. These sera are used both in the diagnostic work and in the control studies, and repre-

sent a saving to the institution, over the cost of equivalent kinds and amounts if purchased, of about $2,500. Sera of these kinds are suitable for use for about one year. Each year the process of preparation must be repeated and new standards obtained.

It is worthy of note that practicing veterinarians are typically unable to give service with reference to poultry diseases. It is partly due to this fact that commercial poultry raisers have sometimes been unable to combat the attacks of contagious disease. The Experiment Station now performs in this diagnostic work a unique service, which is not duplicated by any commercial organization, or, in fact, by any organization in New England. How far the station should go in doing this work is a question. There is no doubt, however, that to date it has resulted in greatly bettering conditions in what is in Massachusetts a large taxpaying agricultural industry.

Insect Conditions of the Year 1921 in Massachusetts.

Department of Entomology,
Dr. H. T. Fernald, Head.

In most ways the year 1921 was an ordinary one, so far as insects are concerned, in this State, only two instances of an unusual character developing.

The first of these was a rather serious but quite local outbreak of the seed-corn maggot (*Hylemyia cilicrura* Rond.) in the onion fields in and near Whately, Hatfield and Sunderland. This insect, so far as any records thus far found go, has never before been reported as injuriously abundant in the State.

The onion fields affected were planted early in April, and because of cold, wet weather the plants were just appearing by the first of May, and were very few in number. Examination at that time showed an abundance of the maggots attacking the sprouts soon after they had started, and working back to the seed itself. From larvæ collected in the fields the adults were raised and their identity verified. It was noticeable that the fields fertilized with cottonseed meal were the ones chiefly infested, no maggots being found in those not so fertilized, even when adjacent to affected ones. No trace of the insect was found in the cottonseed meal itself before its use. It was necessary to replant most of the affected fields, which,

taken together, probably represented over 100 acres, but no injury by the insect was noted in such replanted fields.

The second outbreak was that of the corn ear worm (*Chloridea obsoleta* Fab.). This insect is usually heard from by two or three inquiries about it each year, nearly always from the southeastern part of the State. Last fall the first report was received September 13 from Greenfield, and from then until November 7 letters about it came in large numbers. From the inquiries received, it was present, generally very abundant, in all parts of the State except Berkshire County, where only four locations were learned of, these being one in West Stockbridge, two in Pittsfield and one in Williamstown. It was probably present elsewhere in the county also.

Sweet corn suffered most from this pest, particularly the yellow types, though ensilage, field and pop corn were also attacked. Flint corn was only slightly injured. In some cases a 95 to 100 per cent loss was reported. One case of injury to geraniums was also met with. Through the co-operation of county farm bureau agents, reports of the general, and in many cases the detailed, conditions in the different counties were received, indicating a very general and serious degree of injury. At the Experiment Station living active larvæ of nearly all ages were found on November 5, but ten days later, after two slight snowstorms and the accompanying cold weather, no living, but numerous dead larvæ, were present. Apparently those which had not gone into the ground before this time could not survive this cold weather, and the mortality must have been large.

The striped cucumber beetle was unusually abundant last spring, while the common apple aphids, seemingly because of two heavy frosts just after most of them had hatched, were so reduced in abundance in many parts of the State that nicotine sulfate was omitted from the delayed dormant spray by a number of orchardists without any injury by the aphids resulting. A case of mole crickets feeding on potatoes was reported in September. This insect is seldom observed doing injury in Massachusetts. The birch-leaf skeletonizer, after having been practically absent for about ten years, reappeared abundantly enough to be noticeable in the eastern part of the State, but no more than usual west of Worcester.

Diagnosis of Insect Troubles.

During the year ending the last of November, 1921, diagnosis of 616 cases of insect injury were made on insects and insect damage reported from 226 different villages, towns and cities in the Commonwealth. In addition to this there were 222 telephone or office calls on the same subject, and 39 visits by members of the staff at the request of owners, as well as a large amount of miscellaneous correspondence relating to insecticides and spray machinery. This again is a service which has no commercial counterpart, and which must be rendered by the station or not at all. Farmers as individuals, moreover, are unable oftentimes to either recognize or combat such troubles. Apparently, therefore, the Experiment Station must continue to give this service. The following table is presented, showing the range of subjects treated in this work, and the geographical range from which inquiries come: —

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921.

[Figures in parentheses indicate the number of cases of injury by the same insect reported from the town; where there is no figure only one case of injury was reported.]

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Abbott's sphinx moth	*Sphinx drupiferarum*	1	–	1	Duxbury.
Angle worms	– –	1	1	2	Southwick.
Ants	Formicidæ	21	5	26	Boston (2), Boylston, Boylston Center, Cambridge (2), Clinton, Dedham, Franklin, Holyoke (3), Lowell, Millville, New Bedford, Saugus, Southborough, Watertown, Whitman, Chicago, Ill., Elizabeth, N. J.
Ants, black	Formicidæ	3	–	3	Easthampton, North Dana, Stoughton.
Aphis, root	Aphididæ	1	–	1	Boston.
Apple aphis	*Aphis pomi*	1	–	1	Westfield.
Apple leaf roller	*Archips* sp.	–	1	1	– – –
Apple tree borer	*Saperda candida*	6	–	6	Ashburnham, Becket, Boston, Greenfield, Shelburne Falls, Wakefield.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Asparagus beetles	*Crioceris asparagi*	1	–	1	Sharon.
Asparagus beetles	*Crioceris 12-punctata*	1	1	2	Sharon.
Asparagus miner	*Agromyza simplex*	1	–	1	East Milton.
Bag worms	Psychidæ	1	–	1	Walpole.
Bark beetles	Scolytidæ	1	–	1	Waltham.
Bark miner	– –	–	1	1	– – –
Bean caterpillar	*Plathypena scabra*	1	–	1	Pittsfield.
Bean weevil	*Bruchus obtectus*	24	4	28	Beverly, Bradford, Conway, Fall River, Framingham, Great Barrington, Greenfield, Kingston, Lowell, North Adams, North Wilmington, Peabody, Pittsfield, Reading, Salem, Shelburne Falls, Springfield (2), Turners Falls, Westfield, West Medford, West Natick, Williamsburg, Winchendon.
Bedbug	*Cimex lectularius*	3	7	10	Chicopee, Weymouth, Atkinson, N. H.
Bees and beekeeping	– –	30	58	88	Abington, Amesbury, Amherst, Athol, Becket, Boston (5), Chelsea, Chicopee, East Gardner, Hatchville, Holden (2), Lunenburg, Mansfield, North Brookfield, Orleans (2), Saugus, South Hadley (2), Springfield, Wakefield, Wellesley Farms, Worcester, Medina, Ohio, Toronto, Ont.
Bee diseases	– –	1	1	2	Boston.
Beetles	Coleoptera	2	–	2	Somerville, Hyannis.
Birch-leaf skeletonizer	*Bucculatrix canadensisella.*	2	–	2	Prides Crossing, Worcester.
Blister beetles	Meloidæ	1	–	1	Montgomery.
Blotch leaf miner	*Lithocolletes* sp.	1	–	1	Boston.
Blow fly	*Calliphora vomitoria*	1	–	1	Lynn.
Borers	– –	5	–	5	East Northfield, Lee, Littleton, Palmer, Southborough.
Borers	Cerambycidæ	1	–	1	Lenox.
Bronze-birch borer	*Agrilus anxius*	1	–	1	Cleveland, Ohio.
Brown-tail moth	*Euproctis chrysorrhœa*	5	–	5	Deerfield, Malden, North Wilbraham, Oxford, Rowley.
Brown fruit chafer	*Euphoria inda*	2	–	2	Shelburne Falls, Worcester.
Bruchid larvæ	*Bruchus* sp.	1	–	1	Stanford University, Cal.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Buffalo moth	*Anthrenus scrophulariæ.*	3	-	3	Springfield (2), Waverly.
Cabbage looper	*Autographa brassicæ*	1	-	1	Arlington.
Cabbage maggot	*Hylemyia brassicæ*	3	1	4	Arlington, Northampton, Ottawa, Ont.
Cabbage worms	*Pontia rapæ*	-	1	1	- - -
Calosoma beetles	*Calosoma* sp.	2	-	2	East Bridgewater, Medfield.
Caddis fly larvæ	Trichoptera	3	-	3	Plainfield (2), Ithaca, N. Y.
Carpet beetles	*Anthrenus scrophulariæ.*	1	-	1	Boston.
Caterpillars	Lepidoptera	1	-	1	Wilmington.
Cecropia moth	*Samia cecropia*	5	-	5	Boston, Littleton, Middleton, Waquoit, Woronoco.
Cerambycid pupa	Cerambycidæ	1	-	1	Cambridge.
Chermes sp.	*Chermes* sp.	1	-	1	Holyoke.
Chrysanthemum gall midge.	*Diarthronomyia hypogæa.*	1	1	2	Attleboro.
Cicada killer	*Sphecius speciosus*	1	-	1	Chicopee Falls.
Clear-winged moth	Sesiidæ	1	-	1	Brookfield.
Click beetles	Elateridæ	3	-	3	East Bridgewater (2), Somerville.
Clothes moths	- -	-	4	4	- - -
Clover mite	*Bryobia pratensis*	3	1	4	Boston, Holbrook, Springfield.
Codling moth	*Laspeyresia pomonella*	1	1	2	Harvard.
Confused flour beetles	*Tribolium confusum*	1	-	1	Richford, Vt.
Corn ear worm	*Chloridea obsoleta*	51	8	59	Arlington (2), Attleboro, Baldwinsville, Barre (2), Bernardston, Boston (2), Colrain, East Bridgewater, Fall River, Farnumsville, Fitchburg, Grafton, Greenfield (2), Griswoldville, Holden, Hudson, Ludlow (2), Milton, Monson, Natick, North Plymouth, Oakdale, Pepperell, Petersham, Readville (2), Rutland, Segreganset, Shrewsbury (2), Southbridge South Hadley Center, South Westport, Sterling Junction, Taunton, Turners Falls, Westborough, West Bridgewater, Westfield (2), West Medway, Worcester (2), Albany, N. Y., Little Compton, R. I., Newfane, Vt.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Cottony maple scale	*Pulvinaria vitis*	1	-	1	New York.
Cranberry girdler	*Crambus hortuellus*	2	-	2	East Wareham (2).
Currant aphis	*Myzus ribis*	1	-	1	Greenfield.
Currant borer	*Sesia tipuliformis*	1	-	1	Southborough.
Cutworms	Noctuidæ	4	1	5	East Bridgewater, Melrose, Springfield, Waltham.
Diving water beetle	Dytiscidæ	1	-	1	South Deerfield.
Earwig	Forficulidæ	1	-	1	Portland, Ore.
Eight-spotted forester	*Alypia 8-maculata*	2	-	2	Revere (2).
Elm leaf miner	*Kaliosphynga ulmi*	2	-	2	Ipswich (2).
European corn borer	*Pyrausta nubilalis*	15	3	18	Arlington (2), Boston, East Somerville, Georgetown, Ipswich, Medford, Methuen, Nahant, North Orange, Reading (3), Worcester, Jaffrey Center, N. H.
European fruit Lecanium.	*Lecanium cornis*	1	-	1	Whitman.
Fall canker worm	*Alsophila pometaria*	1	-	1	Raleigh, N. C.
Fall web worm	*Hyphantria cunea*	2	1	3	Cochituate, Waltham.
Fir sawflies	*Lophyrus abietis*	1	-	1	Harvard.
Fish worms	*Lumbricus* sp.	1	-	1	Gardner.
Flat-headed apple tree borer.	*Chrysobothris femorata*	1	-	1	Chelmsford.
Fleas	Siphonaptera	5	1	6	Auburn, Florence, Holyoke, Minot, Pittsfield.
Flea beetles	- -	-	3	3	- - -
Flies	Diptera	5	1	6	Bernardston, Boston, Hubbardston, Pittsfield, Northeast Harbor, Me.
Four-lined plant bug	*Poecilocapsus lineatus*	1	1	2	Newburyport.
Fruit tree bark borer	*Ecoptogaster rugulosus*	1	-	1	Andover.
Fuller's rose beetle	*Aragimus fulleri*	1	-	1	Montrose.
Gall flies	Cynipidæ	1	-	1	Holyoke.
Gall lice	Aphididæ	1	-	1	Lowell.
Gall midge	Itonididæ	3	2	5	Boston (2), Newtonville.
Gall midge flies	Itonididæ	1	-	1	Lenox.
Galls	- -	1	2	3	Madison, N. J.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Garden slugs . .	*Limax* sp.	2	-	2	East Bridgewater, Gardner
Giant water bug .	*Lethocerus americanus*	2	-	2	Lynn, South Lincoln.
Golden oak scale .	*Asterolecanium variolosum*.	1	-	1	Northampton.
Goldsmith beetle .	*Cotalpa lanigera* .	1	-	1	Haverhill.
Gouty oak gall . .	*Andricus punctatus* .	1	-	1	Boston.
Grape-leaf folder .	*Desmia funeralis* .	1	-	1	Beverly.
Grapevine tomato gall	*Lasioptera vitis* . .	1	-	1	Wellesley.
Green fruit worm .	*Xylina* sp. . . .	1	-	1	Groveland.
Green-head fly . .	Tabanidæ	3	-	3	Boston, Gloucester, Ipswich.
Ground beetles .	Carabidæ	1	-	1	Cambridge.
Gypsy moth . .	*Porthetria dispar* .	10	1	11	Amesbury, Boston (3), Harvard, Malden, North Wilbraham, Rowley, Somerville, Wellesley Farms.
Hair worms . .	*Mermis* sp. . . .	2	-	2	Lancaster, Rockland.
House centipede .	*Scutigera forceps* .	1	-	1	Boston.
Ichneumon flies .	Ichneumonidæ . .	1	-	1	Bridgewater.
Imported currant worm.	*Pteronidea ribesii* .	1	-	1	Wellesley.
Ips beetles . .	*Ips* sp.	1	-	1	Greenfield.
Lace bugs . . .	Tingitidiæ	1	-	1	Southwick.
Lady beetles . .	Coccinellidæ . . .	1	-	1	Providence, R. I.
Larch case-bearer .	*Coleophora laricella* .	1	-	1	Northampton.
Larvæ	Lepidoptera . . .	1	-	1	Geneva, N. Y.
Leaf hoppers . .	Cicadellidæ . . .	2	4	6	Boston, South Lincoln.
Leaf rollers . .	*Archips* sp. . . .	2	-	2	Beverly, Malden.
Leaf rollers . .	*Archips argyrospila* .	1	-	1	Newton.
LeConte's sawfly .	*Lophyrus lecontei* .	1	-	1	Ipswich.
Leopard moth . .	*Zeuzera pyrina* . .	2	-	2	East Boston, Framingham.
Lilac borer . .	*Podosesia syringæ* .	1	-	1	Plainville.
Linden mite gall .	*Eriophyes abnormis* .	1	-	1	Madison, N. J.
Long-tailed Thalessa	*Megarhyssa lunator* .	3	1	4	Palmer, Sheldonville, Southwick.
Loopers	Geometridæ . . .	1	-	1	Northampton.
Maggots	*Hylemyia* sp. . . .	1	-	1	Mansfield.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Maple sawfly . .	*Caulacampus acericaulis*.	1	-	1	Boston.
May beetles . .	*Lachnosterna* sp. .	1	-	1	Maynard.
Mediterranean flour moth.	*Ephestia kuhniella* .	-	1	1	- - -
Mealy bugs . .	Dactylopius . .	2	-	2	Dorchester, Summit, N. J.
Mealy bug . .	*Rhizœcus falcifer* .	2	1	3	Summit, N. J., New Brunswick, N. J.
Mellipedes . .	- -	1	-	1	Dover.
Miscellaneous . .	- -	4	30	34	Mansfield, Milford, Mount Hermon, Augusta, Me.
Miscellaneous apple insects.	- -	-	1	1	- - -
Miscellaneous aquatic insects.	- -	-	1	1	
Miscellaneous grain beetles.	- -	-	1	1	- - -
Miscellaneous grape insects.	- -	-	1	1	- - -
Miscellaneous onion pests.	- -	-	1	1	- - -
Miscellaneous pine insects.	- -	-	1	1	- - -
Mice	- -	2	1	3	Andover, Springfield.
Mite galls	Acarina	4	-	4	Monson, New Bedford, Pittsfield, Worcester.
Mite nail galls . .	Acarina	1	-	1	Royalston.
Mites	Acarina	8	3	11	Auburndale, Boston, Brookline, Haverhill, Holden, North Adams, Wakefield, Worcester.
Mite work . .	Acarina	1	-	1	North Wilmington.
Mole crickets . .	*Gryllotalpa* sp. . .	1	-	1	Fairview.
Moles	- -	2	2	4	Longmeadow, North Chester.
Mosquitoes . .	Culicidæ	5	-	5	Boston (2), Wilmington, Washington, D. C., Northeast Harbor, Me.
Mosquito larvæ .	Culicidæ	1	-	1	Andover.
Mossy rose gall . .	*Rhodites rosæ* . .	1	-	1	Lee.
Nematode . . .	*Heterodera radicola* .	1	-	1	Boise, Idaho.
Northern tomato worm.	*Phlegethontius 5-maculata*.	1	-	1	Waltham.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Oak blister midge	Itonididæ	1	-	1	Madison, N. J.
Onion maggot	*Hylemyia antiqua*	3	1	4	Arlington, Nantucket, Atkinson, N. H.
Onion thrips	*Thrips tabaci*	1	2	3	Arlington.
Ox warble	*Hypoderma bovis*	1	-	1	Ludlow, Pa.
Oyster-shell scale	*Lepidosaphes ulmi*	8	1	9	Ayer, Gloucester, Haverhill, Holyoke, Lenox, Upton, Wollaston, Ithaca, N. Y.
Palm insects	- -	-	2	2	- - -
Parasite	Hymenoptera	1	1	2	Springfield.
Peach tree borer	*Aegeria exitiosa*	2	2	4	Hyde Park, West Medford.
Pear-leaf blister mite	*Eriophyes pyri*	12	1	13	Boston, Brier, Brockton, Fitchburg, Hopkinton, Hyde Park, Lowell, Malden, North Wilbraham, Wakefield, Westfield, Providence, R. I.
Pear Psylla	*Psyllia pyricola*	5	-	5	Beverly, Leominster, Rowley, Salem, Wellesley.
Pentatomids	Pentatomidæ	1	-	1	Brookfield.
Pigeon Tremex	*Tremex columba*	1	-	1	Palmer.
Pine bark aphid	*Chermes pinicorticis*	4	-	4	Easthampton, East Northfield, Methuen, Williamstown.
Pine beetles	*Tomicus pini*	-	1	1	- - -
Pine leaf miner	*Paralechia pinifoliella*	-	1	1	- - -
Pine leaf scale	*Chionaspis pinifoliæ*	7	-	7	Chestnut Hill, Hamilton, Greenfield, Millbury, Plainfield, Springfield, Wellesley.
Pine webbers	*Benta* sp.	2	-	2	Boston, Framingham.
Pine web worm	*Benta melanogrammos*	1	-	1	Boston.
Pink boll worm	*Pectinophora gossypiella.*	1	-	1	Albany, N. Y.
Plant lice	Aphididæ	29	5	34	Arlington (2), Ashburnham, Beverly, Billerica, Brookline, Chatham, Conway, Danvers, Essex, Fairview, Groton, Haverhill, Hinsdale, Holliston, Hyde Park, Lenox, Leominster, Lowell, Melrose (2), North Andover, Pocasset, West Roxbury, West Somerville, Worcester, Belgrade Lake, Me., Basking Ridge, N. J., Readsboro, Vt.
Plum curculio	*Conotrachelus nenuphar.*	4	-	4	Belmont, Groveland, Williamstown, Woods Hole.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Polyphemus moth	*Telea polyphemus*	1	-	1	North Conway, N. H.
Poplar borer	*Cryptorhynchus lapathi*	2	-	2	Dorchester, Farnumsville.
Potato and cornstalk borer.	*Papaipema nitela*	7	-	7	Boston, Edgartown (2), Groton Mansfield, Medford Hillside, Turners Falls.
Potato flea beetles	- -	-	1	1	- - -
Potato leaf hopper	*Empoasca mali*	2	1	3	Boston, Madison, Wis.
Potato lice	*Macrosiphum solanifolii.*	1	1	2	Lowell.
Poultry pests	- -	1	-	1	Lexington.
Powder post beetles	*Lyctus* sp.	1	-	1	Dorchester.
Promethea moth	*Callosamia promethea*	1	-	1	Boston.
Psocids	Psocidæ	1	-	1	West Newbury.
Purple-backed cabbage worm.	*Evergestis straminalis*	2	-	2	Athol, Watertown.
Railroad worm	*Rhagoletis pomonella*	1	-	1	Holliston.
Raspberry cane borer	*Oberea bimaculata*	4	-	4	Brookline, Lynn, Salem, Winchendon.
Rats	- -	7	1	8	Blandford, Brockton, Boylston, North Dana, Orange, Petersham, Whitman.
Red bugs	- -	-	1	1	- - -
Red spider	Acarina	1	-	1	Yakima, Wash.
Red squirrels	- -	1	-	1	Essex.
Root borers	- -	-	1	1	- - -
Root maggots	- -	1	1	2	Dorchester.
Rose chafer	*Macrodactylus subspinosus.*	2	1	3	Lenox, Rockport.
Rose curculio	*Rhodites bicolor*	1	-	1	Rockport.
Rose pests (greenhouse).	- -	-	1	1	- - -
Rose scale	*Aulacaspis rosæ*	1	-	1	Mansfield.
San José scale	*Aspidiotus perniciosus*	1	-	1	Greenfield.
Sawflies	*Dolerus collaris*	1	-	1	Boston.
Sawfly larvæ	Tenthredinidæ	1	-	1	Northfield.
Scales	Coccidæ	4	1	5	Palmer, South Braintree, Wakefield, Worcester.
Screw worm fly	*Chrysomyia macellaria*	1	-	1	Dallas, Tex.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Scurfy scale	*Chionaspis furfura*	3	-	3	Boston, Rockport, Boyertown, Pa.
Seed maggots	- -	-	1	1	- - -
Seed corn maggot	*Hylemyia cilicrura*	1	2	3	Milton.
Serpentine park miner	*Marmara* sp.	1	-	1	Northborough.
Sesiid injury	*Sesia pyri*	-	1	1	- - -
Shot hole borer	*Ecoptogaster rugulosus*	1	-	1	Norwood.
Silk worms	*Bombyx mori*	2	-	2	Wareham (2).
Silver fish	*Lepisma saccharina*	4	-	4	Boston (2), Framingham, Greenfield.
Slug caterpillars	Limacodidæ	1	-	1	Dunstable.
Snout beetle	Rhynchophora	1	-	1	Pepperell.
Soft scales	Coccidæ	7	1	8	Greenfield, Lincoln, New Bedford, Rockland, Sterling, Whitman (2).
Sooty fungus (following insect injury).	- -	-	1	1	- - -
Sow bugs	Oniscidæ	2	-	2	East Bridgewater (2).
Sphinx moth	Sphingidæ	2	-	2	Bolton, South Boston.
Spiders	Arachnida	2	-	2	Lunenburg, Worcester.
Spotted garden slug	*Limax* sp.	1	-	1	Fitchburg.
Spruce gall louse	*Chermes abietis*	1	-	1	Pittsfield.
Squash bug	*Anasa tristis*	7	7	14	Dorchester, Mattapoisett, Reading, Rock, South Gardner, Springfield, Stoneham.
Squash vine borer	*Melittia satyriniformis*	25	4	29	Boston, Bradford, Cambridge, Dedham, Fall River, Framingham, Holliston, New Bedford, Reading, Rockland, Southborough, Spencer, Stoneham, Stoughton, Warren, Wayland, West Springfield (2), Weymouth, Whitman, Worcester (5).
Strawberry insect	- -	1	-	1	Albany, N. Y.
Strawberry pests	- -	-	1	1	- - -
Strawberry root worm	*Paria canellus*	1	-	1	Doylestown, Pa.
Stripped cucumber beetle.	*Diabrotica vittata*	14	1	15	Arlington, Attleboro Falls, Boston, Fall River, Framingham, Holliston, Hyde Park, Mattapoisett, Raynham Center, Rockland, Southborough, Stoneham, Wayland, Worcester.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Continued.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis. Letter.	Phone.	Total.	Reported from —
Sugar maple borer	*Plagionotus speciosus*	1	-	1	Chesterfield.
Syrphid fly	Syrphidæ	1	-	1	Amherst.
Tabanid fly	*Tabanus* sp.	1	-	1	Wellesley Farms.
Tarnished plant bug	*Lygus pratensis*	3	1	4	Boston, Hubbardston, Templeton.
Tent caterpillar	*Malacosoma americana*	1	1	2	South Boston.
Termites	Termitidæ	1	2	3	Pocasset.
Terrapin scale	*Lecanium nigrofasciatum.*	4	2	6	Holyoke (2), Northampton, Pittsburg, Pa.
Thrips	Thysanoptera	1	-	1	East Whately.
Thread-waisted wasps	Sphecoidea	1	-	1	Barnard, Vt.
Three-lined potato beetle.	*Lema 3-lineata*	1	-	1	New Bedford.
Thysbe moth	*Hemaris thysbe*	1	-	1	Bridgewater.
Tiger triton	Amphibia	1	-	1	Greenfield.
Tomato worm	*Phlegethontius 5-maculata.*	2	-	2	Cliftondale, Rockland.
Tree hopper	Membracidæ	4	-	4	Grafton, Medway, Springfield, Taunton.
Trumpet grape gall	*Vitis viticola*	1	-	1	Amherst.
Trumpet leaf miner	*Tischeria malifoliella*	2	-	2	Ipswich, Maynard.
Tulip tree scale	*Toumeyella liriodendri*	1	-	1	Westfield.
Two-spotted lady beetle.	*Adalia bimaculata*	1	-	1	Needham.
Walking stick	Phasmidæ	1	-	1	Wrentham.
White flies	Aleyrodidæ	2	2	4	Springfield, Worcester.
White grub	*Lachnosterna* sp.	8	1	9	Amherst, Concord (2), Hudson, Melrose, Shrewsbury, Springfield, West Newbury.
White-marked tussock moth.	*Hemerocampa leucostigma.*	2	-	2	Maynard, Springfield.
White pine weevil	*Pissodes strobi*	2	-	2	Holliston, Silver Lake P. O.
Wireworms	Elateridæ	3	1	4	Medfield, Plymouth, Randolph.
Willow insects	- -	1	-	1	North Truro.
Woolly apple aphis	*Schizoneura lanigera*	6	2	8	Boston, Longmeadow, Northampton, Wakefield, Woburn (2).
Zebra caterpillar	*Mamestra picta*	1	-	1	South Duxbury.
- -	*Aegeria* sp.	1	-	1	Brooklyn, N. Y.

Diagnosis and Advice regarding Insect Injury given in Response to Letters and Telephone Calls, for the Year ending Nov. 30, 1921 — Concluded.

Subject of Inquiry.	Scientific Name.	Requests for Information and Diagnosis.			Reported from —
		Letter.	Phone.	Total.	
- -	*Anomala lucicola* .	1	-	1	South Lincoln.
- -	*Apanteles congregatus*	1	-	1	Waltham.
- -	*Basilarchia archippus*	-	3	3	- - -
- -	*Carabus auratus* .	2	-	2	Melrose Highlands, Winchester.
- -	Hymenoptera . .	1	-	1	Washington, D. C.
- -	Lepidoptera . .	1	-	1	Miniota, Man.
Totals . .	. . . . . .	616	222	838	

The Crop Disease Situation in 1921.

Department of Botany,
Prof. A. V. Osmun, Head.

About the usual number of plant diseases was reported during the year. Six hundred and thirty-nine diagnoses, representing 166 different diseases, were made by the department in response to requests for assistance. However, the season was rather free from serious outbreaks of disease, only three assuming the importance of epidemics.

Weather conditions are a very large controlling factor in the occurrence and prevalence of plant diseases. In general, periods of heavy precipitation and high humidity during the growing season favor outbreaks of disease. This, however, by no means applies to all plant diseases.

The season of 1921 opened with an unusually warm and wet spring which advanced vegetation fully a week beyond normal. The longest period of rainfall of the entire year, extending over seven days, from April 27 to May 3, provided conditions ideal for the discharge and germination of the ascospores of the apple scab fungus, *Venturia inaequalis*, with consequent abundant scab infection of the apple. The most serious outbreak of apple scab in years resulted, and certain varieties,

notably McIntosh, were severely infected, especially where effective spraying was not practiced. A second period of heavy rainfall, accompanied by high temperatures and humidity, occurred in July. During this period there was much secondary scab infection on both fruit and leaves. Had not the apple crop been greatly reduced by a killing frost on May 12, to which further reference will be made, the loss from scab doubtless would have been enormous. This opinion is supported by records of observation in many orchards where a small amount of fruit survived the freeze, and the McIntosh showed from 90 to 100 per cent infection.

The fruit crops were severely damaged by heavy frosts on April 19 and 20 and on May 12. The first freeze injured cherries and plums in the bud, especially in the western part of the State. The damage, however, was not total, resulting only in thinning of the buds; and had not the May 12 freeze, which was general throughout the State, completed the damage, doubtless a good crop of cherries and plums would have been harvested.

Peaches suffered to some extent, but their protective covering of woolly hairs seems to have prevented serious injury from the frosts, and many varieties produced a good crop of fruit.

The damage to apples caused by the low temperatures of April 19 and 20 was not apparent until the opening of the fruit buds about ten days later, when it was observed that many of the buds had been partially injured as indicated by a variety of abnormalities, mostly due to killing of part of the petals and stamens. Few of the buds showing such injury developed normal fruit. The May freeze, which occurred after the petal drop, proved much more disastrous to the apple, killing the newly set fruit outright. From 75 to 90 per cent of the fruit set on Baldwin and McIntosh was ruined. Early varieties, such as Wealthy, Yellow Transparent and Gravenstein, did not suffer to any great extent, probably due to their more advanced development. The damage was greatest in the eastern section of the State.

Tobacco wildfire, caused by *Bacterium tobacum*, was first observed in Massachusetts in 1920, but only three cases were

reported. In the spring of 1921 a general epidemic of the disease occurred in the seed-beds of the Connecticut valley, causing widespread concern among tobacco growers. From the seed-beds the disease was carried to the field, where in many instances it spread with alarming rapidity. No attempt has been made to estimate the loss from this disease, but fields in which infection of the plants was practically total were not uncommon. Naturally, the value of such a crop is very greatly reduced, if indeed the grower is able to find a market for it. Although there has been no thorough study of the relation of weather conditions to occurrence and spread of wildfire, it is known that moisture favors its development, and that rain contributes to its dissemination in the field. It therefore seems probable that the abnormally wet weather of April and May was of major importance in the outbreak and development of the disease in seed-beds, and that the frequent showers and high humidity were to a large degree responsible for its spread and development in the field.

The third disease to appear in epidemic form was the downy mildew of cucumber and melon caused by *Pseudoperonospora cubensis*. This disease is favored by warm, humid and rainy weather occurring after the first of June. It causes no appreciable injury in dry summers. The earliest recorded seasonal date of its appearance in Massachusetts is May 1, 1915. In 1921 it was first noted early in June, when it appeared on cucumbers both in greenhouses and out of doors. From that time, favored by weather conditions of late June and July, it spread and developed rapidly. The resultant damage to the cucumber crop was very heavy, for following the initial outbreak vines were killed and new growth was very generally checked, thus effectively preventing setting and development of new fruit. In a few houses, where Bordeaux mixture was applied under the direction of the department, the disease was held in check and paying crops were harvested. Judging from this year's results it is probable that spraying for cucumber mildew under glass will prove profitable in years when the disease appears. As the spraying was in no instance started until after the mildew appeared on the vines, it seems likely that a preventive spray, that is, one applied prior to

occurrence of the disease, will not be necessary, thus eliminating the necessity of spraying in years of no mildew.

The season was further notable for the almost complete absence of potato late blight which so often proves disastrous to the crop in years when wet weather occurs in August and September. The condition is explained by the fact that the rainfall and humidity both of these months and of October were considerably below normal.

Diagnosis of Plant Diseases.

A statement of the kind and character of the plant diseases for which diagnostic service was requested during the year follows: —

Disease Diagnosis and Advice regarding Control and Eradication given in Response to Letters, Telephone and Personal Calls, for Year ending Nov. 30, 1921.

[Figures in parentheses indicate the number of diagnoses of the same diseases in a town; where there is no figure only one diagnosis was made.]

Host.	Common Name.	Cause.	Number of Diagnoses.	Town.
Almond	Brown-rot	*Sclerotinia* sp.	1	Woburn.
Apple	Bitter pit	Physiological	5	Amherst, Colrain, Goshen, Haydenville, Reading.
	Bitter-rot	*Glomerella rufomaculans* Berk.	2	Amherst, Concord.
	Black-rot	*Physalospora cydoniae* Arn.	18	Amherst (3), Annisquam, Brookfield, Groton (2), Littleton (4), Pittsfield, Rowley, Southborough, West Acton, Westborough, Whitman.
	Brown-rot	*Sclerotinia cinerea* (Pers.) Schroet.	3	Amherst, North Truro, Sunderland.
	Canker	*Physalospora cydoniae* Arn.	8	Amherst (4), Littleton, Lunenburg, South Deerfield, West Acton.
	Canker, bark	*Myxosporium corticolum* Edg.	3	Littleton (3).
	Canker, European	*Nectria cinnabarina* (Tode) Fr.	3	Amherst, Groton, Lunenburg.
	Canker, nail-head	*Nummularia discreta* (Schw.) Tul.	1	Lunenburg.
	Crown-gall	*Pseudomonas tumefaciens* E. F. Smith & Townsend.	2	Athol, Littleton.
	Fire-blight	*Bacillus amylovorus* (Burr.) De Toni	3	Amherst, Westfield, Woods Hole.
	Fruit-spot	*Phoma pomi* Pass.	6	Amherst, Colrain, Greenfield, Haydenville, Littleton, Shelburne, Wareham.
	Frost injury to blossom and fruit.	– – –	12	Amherst, Fitchburg, Groton (2), Haydenville, Littleton (6), West Acton.
	Leaf-spot	*Coniothyrium pirina* (Sacc.) Shel.	1	Pittsfield.
	Leaf-spot	*Physalospora cydoniae* Arn.	5	Amherst (3), Groton (2).
	Rust	*Gymnosporangium macropus* Link	3	Amherst, Taunton, Woods Hole.

	Scab	*Venturia inaequalis* (Cke.) Wint.	61	Amesbury, Amherst (4), Annisquam, Arlington, Ashland, Beverly, Boston, Bridgewater, Brockton, Concord Junction (3), Essex, Falmouth, Fitchburg (4), Groton (6), Hadley, Harvard (5), Holliston, Kendal Green, Littleton (16), Lunenburg, Melrose Highlands, Oxford, Salisbury, South Dennis, Vineyard Haven, Waltham, Watertown, West Acton (2).
	Sooty blotch and fly speck	*Leptothyrium pomi* (Mont. & Fr.) Sacc.	5	Amherst (3), Haydenville, Sunderland.
	Spongy dry-rot	*Volutella fructi* Stevens & Hall	2	Amherst, Boston.
	Sun-scald	Physiological	3	Lunenburg, Rowley, Touisset.
	Winter injury	– – –	2	Amherst, Groton.
Ash	Disease not determined	– – –	1	Topsfield.
	Rust	*Puccinia fraxinata* (Link) Arthur	2	Ipswich, Wareham.
Asparagus	Crown-rot	*Fusarium* sp.	7	Amherst (2), Arlington, Concord, Lexington, Littleton (2).
	Rust	*Puccinia asparagi* DC.	5	Amherst (2), Lexington, Littleton, Sunderland.
Aster	Dry stem-rot	*Fusarium* sp.	4	Amherst, Boston, Cambridge, North Wilmington.
	Root-rot	*Rhizoctonia* sp.	1	Amherst.
	Yellows	Physiological	3	Amherst, Foxborough, West Brookfield.
Barberry	Rust	*Puccinia graminis* Pers.	3	Amherst, Belchertown, Leverett.
Barley	Smut	*Ustilago Hordei* (Pers.) Kel. & Sw.	1	Amherst.
	Smut	*Ustilago nuda* (Jens) Kel. & Sw.	1	Amherst.
Bean	Anthracnose	*Colletotrichum lindemuthianum* (Sacc. & Magn.) B. & C.	8	Amherst (6), Arlington, West Millbury.
	Blight	*Pseudomonas phaseoli* Erw. Smith	3	Amherst (2), Arlington.
	Rust	*Uromyces appendiculatus* (Pers.) Link	2	Arlington, Manchester.
	Stem and root-rot	*Rhizoctonia* sp. and *Fusarium* sp.	5	Amherst (4), Lexington.

Disease Diagnosis and Advice regarding Control and Eradication given in Response to Letters, Telephone and Personal Calls, for Year ending Nov. 30, 1921 — Continued.

Host.	Common Name.	Cause.	Number of Diagnoses.	Town.
Beet	Leaf-spot	*Cercospora beticola* Sacc.	2	Amherst, Lexington.
Blackberry	Anthracnose	*Gloesporium venetum* Speg.	2	Amherst, Littleton.
	Crown-gall	*Pseudomonas tumefaciens* E. F. Smith & Townsend.	1	Amherst.
	Leaf-spot	*Septoria rubi* Westd.	1	Amherst.
	Rust	*Gymnoconia peckiana* (Howe) Tranz	1	Northampton.
Cabbage	Brown-rot	*Pseudomonas campestris* (Pammel) Erw. Smith	1	Arlington.
	Clubroot	*Plasmodiophora brassicae* Wor.	3	Amherst, Gardner, Great Barrington.
	Disease not determined	– – –	4	Pittsfield (4).
	Leaf-spot	*Alternaria brassicae* (Berk.) Sacc.	2	Arlington, Lexington.
	Soft-rot	*Bacillus carotovorus* Jones	1	Amherst.
Carnation	Root-rot	*Rhizoctonia solani* Kühn.	2	Amherst, Northborough.
	Rust	*Uromyces Caryophyllinus* (Schrank) Wint.	1	Amherst.
	Wilt	*Fusarium* sp.	3	Amherst, Manchester, Northborough.
Carrot	Blight	*Macrosporium* sp.	3	Amherst, Lexington, Marblehead.
	Soft-rot	*Bacillus carotovorus* Jones	3	Amherst, Lexington, Marblehead.
Catalpa	Leaf-spot	*Phyllosticta catalpae* Ell. & Mart.	1	Holyoke.
Cedar	Rust	*Gymnosporangium macropus* Link	1	Woods Hole.

Celery	Crown-rot	*Bacillus carotovorus* Jones	2	Amherst, Lexington.
	Early-blight	*Cercospora apii* Fr.	2	Amherst, West Springfield.
	Late-blight	*Septoria Petroselini* Desm. var. *Apii* Br. & Cav.	5	Amherst, Arlington, Lexington, West Springfield, Worcester.
Cherry	Brown-rot	*Sclerotinia cinerea* (Pers.) Schroet.	2	Amherst, Worcester.
	Leaf-spot	*Coccomyces hiemalis* Higgins	3	Amherst (3).
Chestnut	Canker	*Endothia parasitica* (Murrill) A. & A.	7	Amherst (2), Goshen, Granby, Prescott, South Deerfield, Sunderland.
	Disease not determined	— — —	1	Horse Shoe, N. C.
Chrysanthemum	Black spot	*Cylindrosporium Chrysanthemi* Ell. & Dearn.	1	Amherst.
Corn	Rust	*Puccinia Sorghi* Schw.	2	Amherst (2).
	Smut	*Ustilago Zeae* (Beckm.) Ung.	3	Amherst (3).
Cucumber	Downy mildew	*Pseudoperonospora cubensis* (B. & C.) Rostew.	12	Amherst (4), Arlington (4), Deerfield, Harvard, Lexington, Sunderland.
	Root-knot	Nematode worms	2	Amherst, Arlington.
	Stem-rot	*Sclerotinia Libertiana* Fckl	4	Amherst, Arlington (3).
	White pickle or mosaic	Physiological	4	Medford (2), South Deerfield, South Hadley.
	Wilt	*Bacillus tracheiphilus* Erw. Smith	1	South Hadley.
Currant	Anthracnose	*Pseudopeziza Ribis* Kleb.	3	Amherst, Millis, Rowley.
	Rust	*Aecidium Grossulariae* Schum.	1	Haverhill.
Eggplant	Rot	*Botrytis fascicularis* (Cda.) Sacc.	2	Amherst, Braintree.
	Wilt	*Verticillium* sp.	3	Amherst, Braintree, Lexington
Elm	Heart-rot	*Polyporus sulphureus* Fr.	1	Northampton.
	Leaf-spot	*Dothidella ulmea* (Schw.) Ell. & Ev.	3	Amherst, Groton, Ludlow.
	— — —	Saprophytic polypori	1	Holyoke.

Disease Diagnosis and Advice regarding Control and Eradication given in Response to Letters, Telephone and Personal Calls, for Year ending Nov. 30, 1921 — Continued.

Host.	Common Name.	Cause.	Number of Diagnoses.	Town.
Gladiola	Bulb-rot	Cause undetermined	1	Longmeadow.
Grape	Anthracnose	*Gloeosporium ampelophagum* Sacc.	1	Boston.
	Black-rot	*Guignardia Bidwellii* (Ell.) Viala & Ravaz.	8	Amherst, Boston, Farnumsville, Lunenburg, Millbury (2), Princeton, Randolph.
Grass (lawn)	- - -	*Rhizoctonia* sp.	4	Amherst (2), Newburyport, Pittsfield.
Hawthorn	Leaf-blight	*Entomosporium thumenii* (Cke.) Sacc.	3	Norton, Segreganset, Worcester.
	Rust	*Gymnosporium clavariaeforme* (Jacq.) Rees.	2	Cambridge, Taunton.
Hollyhock	Rust	*Puccinia malvaccarum* Mont.	7	Amherst, Hyannis, Rowe, South Dartmouth, Still River, West Medway, West Newton.
Horsechestnut	Leaf-blight	*Guignardi aesculi* (Pk.) Stew.	2	Amherst, Williamstown.
Iris	Root-rot	*Bacillus carotovorus* Jones	1	Amherst.
Ivy	Leaf-spot	*Guignardi Bidwellii* (Ell.) V. & R.	1	Marion.
Lettuce	Bottom-rot	*Rhizoctonia solani* Kühn.	3	Amherst, Arlington (2).
	Drop	*Sclerotinia Libertiana*	16	Arlington (12), Belmont, Lexington, Watertown, West Springfield.
	Gray mold	*Botrytis cinerea* Pers.	4	Arlington (3), Belmont.
	Root-knot	Nematode worms	2	Amherst, Arlington.
Lilac	- - -	Frost injury	1	Groton.
Linden	Leaf-spot	*Gloeosporium* sp.	1	Amherst.
Maple	Black spot	*Rhytisma acerinum* (Pers.) Fr.	3	Amherst (2), Pittsfield.
	Leaf-spot	*Phyllosticta* sp.	1	Pittsfield.
	Sun-scald	Physiological	3	Holyoke, Palmer (2).

Melon	Anthracnose	*Colletotrichum lagenarium* (Pers.) Ell. & Halst.	1	Woods Hole.
Oak	Leaf-spot	*Vermicularia* sp.	1	Pittsfield.
Oats	Crown-rust	*Puccinia coronata* Cda.	1	Manchester.
	Leaf-blight	*Helminthosporium inconspicuum* (C. & Ell.)	1	Dalton.
	Smut	*Ustilago Avenae* (Pers.) Jens.	3	Amherst, Goshen, Greenfield.
Onion	Damping-off	*Pythium de Baryanum* and *Fusarium* sp.	4	Amherst, Leverett, Sunderland (2).
	Leaf-spot	*Macrosporium* sp.	2	Sunderland (2).
	Neck-rot	*Botrytis* sp.	8	Amherst (2), Hadley, Hatfield, Sunderland (4).
	Smudge	*Vermicularia circinans* Berk.	1	Amherst.
	Smut	*Urocystis cepulae* Frost	14	Amherst (3), Atkinson, N. H., Leverett, North Hadley, South Deerfield (2), Sunderland (6).
Parsnip	Soft-rot	*Bacillus carotovorus* Jones	2	Amherst (2).
Pea	Root-rot	*Fusarium* sp.	7	Amherst (4), Brockton, Hingham, Rockland.
Peach	Brown-rot	*Sclerotinia cinerea* (Pers.) Schroet.	5	Amherst, East Taunton, Hingham, Manchester, Squantum.
	Canker and gummosis	*Sclerotinia cinerea* (Pers.) Schroet.	4	Amherst (2), Groton, Littleton.
	Leaf-curl	*Exoascus deformans* (Berk.) Fckl.	3	Amherst, Milton, Woods Hole.
	Scab	*Cladosporium carpophilum* Thüm.	1	East Taunton.
Pear	Crown-gall	*Pseudomonas tumefaciens* Erw. Smith & Townsend.	1	Boston.
	Fire-blight	*Bacillus amylovorus* (Burr.) De Toni	2	Amherst (2).
	Scab	*Venturia Pyrina* Aderh.	3	Amherst, Provincetown, Quincy
	Tip-burn	Physiological	1	Cambridge.
Peony	Stem-rot	*Botrytis Paeoniae* Oud.	1	Touisset.

Disease Diagnosis and Advice regarding Control and Eradication given in Response to Letters, Telephone and Personal Calls, for Year ending Nov. 30, 1921 — Continued.

Host.	Common Name.	Cause.	Number of Diagnoses.	Town.
Phlox	Powdery mildew	*Erysiphe cichoracearum* DC.	2	Amherst, Canaan, N. H.
Pine	Disease undetermined	– – –	1	Medford.
	Sun-scald	Physiological	6	Amherst, East Northfield, Greenfield, Shelburne, South Hadley, Sunderland.
Plum	Black knot	*Plowrightia morbosa* (Schw.) Sacc.	4	Amherst, Cliftondale, Lincoln, South Weymouth.
	Brown-rot	*Sclerotinia cinerea* (Pers.) Schroet.	4	Amherst (2), Arlington, Littleton.
	Leaf-spot	*Coccomyces Prunophoroe* Higgins	2	Amherst (2).
Popcorn	Ruptured kernel	Probably due to crossing with field corn	1	Walpole.
Poplar	Canker	*Dothichiza populea* S. & B.	2	Boston (2).
Potato	Black heart	Physiological	3	Amherst, New Salem, Worcester.
	Early-blight	*Macrosporium solani* E. & M.	2	Amherst (2).
	Hollow heart	Physiological	2	Amherst, Brighton.
	Late blight	*Phytopththora infestans* (Mont.) deBary	2	Amherst (2).
	Leaf-roll	Physiological	5	Amherst (2), Cummington, Goshen, Sunderland.
	Mosaic	Physiological	6	Amherst (4), Cummington, Goshen.
	Scab	*Actinomyces chromogenus* Gasperini	2	Amherst, Falmouth Heights.
	Scurf or Rhizoctonia	*Corticium vagum* B. & C. var. *Solani* Burt	3	Amherst (2), Sunderland.
	Soft-rot	*Bacillus* sp.	2	Amherst (2).
	Tip-burn	Physiological	7	Amherst (3), Hadley (2), Holliston, Sunderland.

Quince	Rust	*Gymnosporium clavipes* C. & P.	5	Amherst, Boston, Granby, Hadley, Montague.
Raspberry	Anthracnose	*Gloeosporium venetum* Speg.	2	Athol, Hudson.
	Cane-blight	*Coniothyrium Fuckelii* Sacc.	1	Boston.
	Crown-gall	*Pseudomonas tumefaciens* Erw. Smith & Townsend.	2	Haverhill, Westdale
	Leaf-spot	*Septoria Rubi* West	1	Enfield.
	Spur-blight	*Mycosphoerella rubina* (Pk.) Jacz.	2	West Acton, Haverhill.
	Yellows	Physiological	2	Amherst, Plymouth.
Rose	Black spot	*Actinonema Rosae* Wolf	2	Hadley, Willimantic, Conn.
	Crown-gall	*Pseudomonas tumefaciens* Erw. Smith & Townsend.	2	Hadley, Boston.
	Powdery mildew	*Sphaeorthera pannosa* (Wallr.) Lev.	4	Amherst, Gloucester, Groveland, Holden.
Snapdragon	Rust	*Puccinia antirrhini* D. & H.	1	Northampton.
	Wilt	*Verticillium* sp.	1	Northampton.
Spinach	Disease undetermined	– – –	3	Arlington, Lexington, Worcester.
Squash	Black mold	*Mucor mucedo* L.	1	Amherst.
	Downy mildew	*Pseudoplasmopora cubensis* B. & C.	1	Harvard.
Strawberry	Fruit-rot	*Rhizopus nigricans* Ehr.	1	Amherst.
	Gray mold	*Botrytis* sp.	1	Amherst.
	Leaf-spot	*Mycosphaerella fragariae* (Tul.) Lin.	4	Amherst, Montague, North Wilmington, Standish.
	Root-rot	Undetermined	3	Amherst, Caryville, Montague.
Sweet pea	Bud drop	Physiological	2	Amherst, Arlington.
Sycamore	Anthracnose	*Gnomonia Veneta* (Sacc. & Speg.) Kleb.	2	Amherst (2).

Disease Diagnosis and Advice regarding Control and Eradication given in Response to Letters, Telephone and Personal Calls, for Year ending Nov. 30, 1921 — Concluded.

Host.	Common Name.	Cause.	Number of Diagnoses.	Town.
Tobacco	Damping-off	*Pythium de Baryanum* Hesse.	5	Hatfield, North Hadley, Southwick, Sunderland, Westfield.
	Mosaic	Physiological	2	South Deerfield (2).
	Root-rot	*Thielavia basicola* (B. & Br.) Zopf.	4	Hatfield, North Hatfield, South Deerfield, Sunderland.
	Wildfire	*Bacterium tobacum* Wolf & Foster	88	Agawam, Amherst (2), Congamond (2), Conway, Deerfield (6), Feeding Hills, Hadley (3), Hatfield (8), Haydenville, Hillsborough (2), North Amherst (3), North Hadley (7), Northfield, North Sunderland, South Deerfield (7), Southwick (11), Sunderland (6), Westfield, West Hatfield, West Suffield, Conn., West Whately (3), Whately (19).
Tomato	Anthracnose	*Colletotrichum Phomoides* (Sacc.) Chester	1	Amherst.
	Blossom end rot	Physiological	2	Amherst, Arlington.
	Early-blight	*Macrosporium solani* Ell. & Mart.	1	Amherst.
	Leaf-spot	*Septoria Lycopersici* Speg.	1	Amherst.
	Mosaic	Physiological	2	Amherst, West Springfield.
	Root-galls	Nematode worms	2	Amherst, Arlington.
	Wilt	*Fusarium* sp.	1	Arlington.
	Winter-blight	Bacterial	3	Amherst, Arlington, Berlin.
Turnip	Black-rot	*Pseudomonas campestris* (Pam.) E. F. Sm.	1	Millers Falls.
	Clubroot	*Plasmodiophora brassicae* Wor.	1	Amherst.
	Disease undetermined	- - -	1	Millers Falls.

Violet	Root-knot	Nematode worms	1	Amherst.
Walnut (black)	Disease undetermined	– – –	1	South Deerfield.
Wisteria	Sun-scald	Physiological	1	Rowe.
Total			639	

METEOROLOGICAL OBSERVATIONS.

DEPARTMENT OF METEOROLOGY,

PROF. J. E. OSTRANDER, HEAD.

Annual Summary for 1921.

Pressure (in Inches).

Maximum reduced to freezing	30.56, Jan. 19, 10 A.M.
Minimum reduced to freezing	29.03, Oct. 20, 3 P.M.
Maximum reduced to freezing and sea level	30.90, Jan. 19, 10 A.M.
Minimum reduced to freezing and sea level	29.33, Oct. 20, 3 P.M.
Mean semi-daily reduced to freezing and sea level	30.040
Annual range	1.57

Air Temperature (in Degrees Fahr.).[1]

Highest	96.0, June 22, 3 P.M.
Lowest	—6.0, Jan. 19, 7 A.M.
Mean hourly	49.5
Mean of means of maximum and minimum	49.8
Mean sensible (wet bulb)	44.4
Annual range	102.0
Highest mean daily	80.6, July 8
Lowest mean daily	4.0, Jan. 19
Mean maximum	60.5
Mean minimum	39.0
Mean daily range	21.5
Greatest daily range	48.5, Oct. 15
Least daily range	3.0, Nov. 19

Humidity.

Mean dew point	40.4
Mean force of vapor	405
Mean relative humidity	76.0

Wind.

Prevailing direction	W. S. W.

[1] Temperature in ground shelter.

Summary.

South southwest	22 per cent
North	10 per cent
Northwest	10 per cent
Other directions	58 per cent
Total movement	52,373 m.
Greatest daily movement	465 m., Jan. 25
Least daily movement	13 m., July 4
Mean daily movement	143 m.
Mean hourly velocity	6.0 m.

Maximum pressure per square foot, 29.0 lbs., = 76 m. per hour, Dec. 18, 5 A.M. W.S.W.

Maximum velocity for 5 minutes, 36 m. per hour, Nov. 5, 7 A.M. N.W.; Dec. 18, 7 A.M. W.S.W.

PRECIPITATION (IN INCHES).

Total precipitation, rain or melted snow	42.22
Snow total in inches	37.5
Number of days on which .01 or more rain or melted snow fell	131

WEATHER.

Mean cloudiness observed	50 per cent
Total cloudiness recorded by sun thermometer	1,819 hrs. = 40 per cent.
Number of clear days	126
Number of fair days	141
Number of cloudy days	98

BRIGHT SUNSHINE.

Number of hours recorded	2,695 hrs. = 60 per cent

DATES OF FROSTS.

Last	May 12
First	Oct. 9

DATES OF SNOW.

Last	April 18
First	Nov. 7
Total days of sleighing	28

GALES OF 50 OR MORE MILES PER HOUR.

Mar. 29, 50m., N.; Nov. 5, 61m., N.W.; Dec. 3, 54m., W.N.W.; Dec. 18, 76m., W.S.W.

REPORT OF THE TREASURER.

FRED C. KENNEY.

United States Appropriations, 1920–21.

		Hatch Fund.	Adams Fund.
Dr.			
To receipts from the Treasurer of the United States, as per appropriations for the fiscal year ended June 30, 1921, under acts of Congress approved March 2, 1887, and March 16, 1906,		$15,000 00	$15,000 00
Cr.			
Adams:			
By salaries	$14,171 24		
labor	512 82		
seeds, plants and sundry supplies	98 88		
fertilizer	142 48		
feeding stuffs	8 45		
scientific apparatus and specimens	66 13		
	$15,000 00		15,000 00
Hatch: —			
By salaries	$14,902 50		
labor	97 50		
	$15,000 00	15,000 00	

State Appropriations, 1920–21.

Cash balance brought forward from last fiscal year	—
Cash received from State Treasurer	$76,430 03
fees	15,095 88
sales	10,128 13
miscellaneous	343 56
	$101,997 60
Cash paid for salaries	$41,957 85
labor	17,115 23
publications	1,327 74
postage and stationery	2,017 22
freight and express	266 50
heat, light, water and power	525 08
chemicals and laboratory supplies	1,388 81
seeds, plants and sundry supplies	2,688 64
fertilizer	1,079 18
feeding stuffs	1,611 83
library	691 98
tools, machinery and appliances	952 09
furniture and fixtures	112 45
scientific apparatus and specimens	269 83
live stock	1,143 00
traveling expenses	2,346 35
contingent expenses	30 00
buildings and land	906 25
Remitted to State Treasurer	25,567 57
Total	$101,997 60

BULLETIN No. 201.

DEPARTMENTS OF CHEMISTRY, ENTOMOLOGY, AND BOTANY.

INSECTICIDES AND FUNGICIDES FOR FARM AND ORCHARD CROPS IN MASSACHUSETTS.

BY E. B. HOLLAND, A. I. BOURNE AND P. J. ANDERSON.

The successful production of farm and orchard crops depends in large measure on the protection afforded against injurious insects and bacterial and fungous diseases. Obviously there is no remedy — that is, no panacea for all noxious insects and parasitic diseases of plant life — that would not also destroy the host. The method of treatment, therefore, must be essentially specific, and for convenience will be divided into three major groups: (A) Insecticides, (B) Fungicides, and (C) Combined applications.

A. INSECTICIDES.

The injurious insects that infest the crops under consideration are of two distinct types as determined by their mode of feeding: *i.e.*, biting and sucking. The former type consumes organized tissue, and the latter draws sustenance from plant juices. The respective treatment of the two types is necessarily different and warrants a division of insecticides into (I) Stomach poisons for biting insects, and (II) Contact poisons for sucking insects. The stomach poisons of to-day owe their origin largely to the Colorado potato beetle, and the contact poisons to the San José scale.

The acknowledged requisites for an insecticide are —

1. Non-toxicity as to plant.
2. Effectiveness in destroying the insect.
3. Adhesiveness or persistence under all weather conditions.
4. Fineness of particles and a light flocculent character (when insoluble) to insure a high power of suspension and uniform distribution.
5. Ability to indicate the surface covered.
6. Reasonable cost.

The factors that facilitate distribution naturally differ somewhat in soluble and insoluble products, dust and spray applications. These attributes comprise a standard for judging insecticides, and apply in principle to fungicides as well.

I. STOMACH POISONS FOR BITING INSECTS.

Nearly all stomach poisons of the present time are compounds of arsenic, and this has led to the general use of the term "arsenicals" for this group of insecticides. Very little work has been done, and still less has been published, in regard to the exact nature of the toxic action of arsenic on the physical structure of insects. The fact that this action takes place and the rapidity of its killing effect upon the insects in question have been practically the only points to which writers have hitherto given their attention.

The sprays consist of minute particles of the poison, suspended in the water or other vehicle, which are deposited upon the food of the insect and adhere to it upon drying.

1. Arsenicals.

There are two forms of arsenicals to be considered: —

1. The lower or arsenous oxide, or arsenic trioxide (white arsenic) (As_2O_3).
2. The higher or arsenic oxide, or pentoxide (As_2O_5).

When these two oxides are combined with bases, the former yields the so-called (*a*) Arsenites, and the latter (*b*) Arsenates.

Arsenites as a class are noticeably more active poisons than the arsenates, but are relatively unstable and more likely to cause injury to the plant, and for that reason they have been largely supplanted.

Depending on the form in which the arsenic may be present, arsenicals are sold on a guaranty in which the amount of arsenic (the active principle) may be stated in the following terms: —

Percentage of arsenous oxide or arsenic trioxide (As_2O_3) or white arsenic.
Percentage of arsenic pentoxide (As_2O_5).
Percentage of elemental arsenic (metallic arsenic).

The first form is used in guaranties of Paris green, whereas either the second or third form is used in stating guaranties of arsenates. Notwithstanding the fact that the killing power of arsenates and arsenites varies in rapidity, and possibly in final extent, the percentage of metallic arsenic seems to be the only common denominator by which to compare one arsenical with another.

(*a*) **Arsenites.**

A number of arsenites have been placed on the market at one time or another. Paris, Schweinfurt, or Emerald green, a well-known poisonous pigment, was first used about 1868 (1).[1] This date, therefore, marks the

[1] Numbers in parentheses indicate literature cited, which will be found on pages 35–37.

beginning of the era in which active agents supersede the old-time repellents (2), which were usually characterized by offensive (both odor and taste) or caustic rather than poisonous properties. Some, however, may have possessed value as contact poisons. In 1875 Scheele's green (3) was introduced, in 1877 London purple (4), and in 1891 calcium arsenite (5).

There are several other commercial products which are worthy of mention, although many of them contain soluble arsenic, and in some cases uncombined white arsenic may have been a constituent. Gray arsenoid was a mixture of calcium and copper arsenites. Barium arsenite or white arsenoid was essentially a mixture of barium compounds and of arsenic rather than a true salt. Zinc arsenite was employed by potato growers in certain localities for a few seasons. Laurel green was a mixture of copper arsenite, gypsum and green sand. Paragrene was a mixture of Paris green and gypsum.

Paris green, because of its quick action and comparative safeness when applied with lime, still maintains a place in the list of recommended arsenicals, but has certainly lost much of its former prominence.

(1) *Paris Green.*

Composition. — Paris green is a copper aceto-arsenite for which the formula of Eugene Ehrmann is generally accepted: —

$$(CH_3COO)_2\,Cu.3Cu\,(AsO_2)_2$$

As a double salt it may be said to consist of 1 part of copper acetate and 3 parts of copper metarsenite. The composition of the theoretical salt is as follows: —

		Per Cent.
Cupric oxide (CuO),		31.385
Arsenous oxide (As_2O_3),		58.550
Equivalent to metallic arsenic (As) (per cent),	44.350	
Ratio CuO : As_2O_3,	1 : 1.866	
Acetic anhydride $(CH_3CO)_2O$,		10.065
		100.000

Stability. — While Paris green is nominally insoluble in water, it is in reality unstable, and breaks down under continuous percolation of water, with the liberation of soluble and hence injurious arsenic. Carbonic acid, ammonia and certain alkaline salts likewise tend to increase the solubility of the arsenic. Since conditions which control the presence of these substances cannot always be foretold, it is always well to add milk of lime to Paris green to prevent arsenical injury. It does this by uniting with the free and loosely combined arsenic to form calcium arsenite, which is insoluble and hence non-injurious to the foliage.

Form of Guaranty. — The form of guaranty under which Paris green is sold is as follows: —

	Per Cent.
Total arsenous oxide, not less than	50.00
Water soluble arsenous oxide, not more than	3.50

The statement of total arsenous oxide in the above guaranty may be taken as representing the effectiveness of the material in terms of the killing principle which it contains. The statement of soluble arsenous oxide indicates the maximum amount of injurious compounds of arsenic.

The above guaranty corresponds to the Federal standard. Paris green as offered for sale in this State fully meets this guaranty.

To summarize: Paris green is of high arsenic content, and that in the form of arsenous oxide, nominally insoluble in water, but unstable, hydrolyzing readily, and likely to cause injury unless applied with lime. It is an active poison with a low power of suspension, but admitting of reasonable distribution; a poor indicator without lime of the leaf surface covered; and of fair adhesiveness and persistence under average weather conditions.

(*b*) **Arsenates.**

As a group arsenates are rapidly supplanting arsenites, because they have greater stability and are less likely to injure foliage. Of the five arsenates which at one time or another have been used in practice or have been sold in commerce, lead arsenate, developed in 1894 (6), is unquestionably the most satisfactory. Calcium arsenate, first manufactured about 1912,[1] is serviceable, but has a more limited field of usefulness. Magnesium arsenate has been on the market for but two seasons, while the arsenates of zinc and iron are of but minor importance.

(1) *Lead Arsenate.*

F. C. Moulton (7), chemist for the Massachusetts Gypsy Moth Commission, was the first to prepare arsenate of lead for insecticide purposes in 1892. The work was continued by F. J. Smith (8), who studied various matters pertaining to the manufacture, and stated that ordinary spray material was not a single salt, but a mixture of neutral and acid arsenates. Lead arsenate paste appears to have been first prepared commercially about 1895 by the Merrimac Chemical Company of Boston, under the trade name of Swift's arsenate of lead. Disparene, manufactured by the Bowker Insecticide Company of Boston, followed soon after. Dry lead arsenate (Electro) was prepared as an insecticide by the Vreeland Chemical Manufacturing Company of New York about 1909. The California Experiment Station mentioned a dry product in 1903, but gave no information as to its source. Dry, *bulky* acid lead arsenate was first prepared in 1912 by the Corona Chemical Company of Milwaukee, Wis.

There appear to be three different lead arsenate salts, as follows: —

1. Acid lead arsenate, $PbHAsO_4$. This is the lead arsenate ordinarily sold in New England.
2. Neutral lead arsenate, $Pb_3(AsO_4)_2$.
3. Basic lead arsenate (9), $Pb_5OH(AsO_4)_3$.

---

[1] Correspondence from manufacturers on file.

A few writers claim that pyroarsenate, $Pb_2As_2O_7$, may occur in commercial products, but the evidence at hand does not support the assertion.

Composition. — The composition of theoretical acid, neutral and basic lead arsenates is as follows: —

	Acid Lead Arsenate (Per Cent).		Neutral Lead Arsenate (Per Cent).		Basic Lead Arsenate (Per Cent).	
Lead oxide (PbO),		64.291		74.440		75.924
Arsenic pentoxide (As_2O_5),		33.114		25.560		23.463
Equivalent to metallic arsenic (As) (per cent).	21.590		16.667		15.299	
Ratio As_2O_5 : PbO,	1:1.942		1:2.912		1:3.236	
Water of combination,		2.595		0.000		0.613
		100.000		100.000		100.000

From the above table it is evident that the acid lead arsenate as it is sold in New England is considerably more concentrated than is either the neutral lead arsenate or the basic lead arsenate. From economic standpoints alone this matter is of importance.

Physical Properties. — These products, whether acid or mixed acid and neutral arsenates, are usually smooth white pastes of finely divided, amorphous particles, less than 1 μ in size, with a good power of suspension and exceptional adhesiveness. The so-called neutral salt has almost invariably been a mixture of acid and neutral, and very little has been marketed. The physical structure of the neutral salt, or of mixtures containing considerable neutral lead arsenate, is rather inferior to that of the acid salt, and the basic material used in southern California is said to be relatively coarse and granular. The power of suspension is injured by drying or freezing. These pastes are compact and "greasy," but fairly miscible with water when properly handled. The acid salt is less compact, has a lower specific gravity and higher power of suspension, and is a more active poison than the neutral or basic. The specific gravity of the acid salt (amorphous form) (10) at 15/15° C. is 5.93, the neutral (10), 7.32, and the basic (11), at 20/4° C., 7.105.

More recently the dry powders have displaced the pastes in large measure at a material saving in cost of containers, transportation, possible leakage and danger of injury on storage. This product is a white, bulky (fluffy) powder of fine amorphous particles, with a very high power of suspension and excellent adhesiveness. The "old type" dry acid arsenate ran about 40 cubic inches to the pound, and the "new type" 70 to 80 cubic inches. The neutral and basic products are more dense, but actual figures are not available, as they are seldom if ever marketed in dry form. The product, as offered in Massachusetts markets, is essentially the acid arsenate. It is more readily miscible with water than the paste, and a time saver in this respect.

Stability. — Acid and neutral lead arsenates are practically insoluble in cold water, but continuous percolation may cause decomposition. Hot water is more effective, but may cause slight hydrolysis, particularly of the acid salt. Dilute solutions of sodium carbonate, sodium chloride and sodium sulfate have been shown (12, 13) to increase the solubility of the arsenic, especially where the common acid lead arsenate is used. Stability may be obtained by adding calcium hydroxide (milk of lime) to acid or neutral arsenate. The former will necessarily require more base to afford like protection. The basic salt sold in the West contains only about 20 to 22 per cent of arsenic pentoxide on a dry basis.

Form of Guaranty. — The usual form of guaranty under which dry lead arsenate is sold is substantially as follows: —

		Per Cent.
Active ingredients: —		
Lead arsenate, not less than		98.00
Total arsenic pentoxide, not less than	31.00	
Total arsenic (as metallic), not less than	20.20	
Inert ingredients, not more than		2.00
		100.00
Water Soluble.		
Soluble arsenic pentoxide, not more than		0.75
Soluble arsenic (as metallic), not more than		0.50

As in the case of Paris green, an article is desired which contains a high percentage of total arsenic with a low maximum percentage of soluble arsenic. It is well to note further that in the above guaranty the essential statements are those italicized. The other statements made simply repeat this information in different form.

The Federal standard (14) for commercial lead arsenate specifies not more than 50 per cent of water, nor less than 12.50 per cent of total arsenic pentoxide (equivalent to 8.15 per cent metallic arsenic), and not more than 0.75 per cent of arsenic pentoxide soluble in water (equivalent to 0.49 per cent metallic arsenic).

To maintain a high standard of purity the product, whether paste or powder, should be substantially free from carbonate, chloride, sulfate and acid soluble matter, and should not contain more than 2.50 per cent, on a dry basis, of water soluble by-products. The dry acid lead arsenate sold in the East is usually guaranteed to contain 30 or 31 per cent of total arsenic pentoxide (equivalent to 19.56 or 20.21 per cent metallic arsenic), and not more than 0.75 or 1 per cent of arsenic pentoxide soluble in water (equivalent to 0.49 or 0.65 per cent metallic arsenic). The paste is usually guaranteed to contain 15 per cent arsenic pentoxide (equivalent to 9.78 per cent metallic arsenic), and not more than 0.75 per cent arsenic pentoxide soluble in water.

To summarize: Lead arsenate is of low arsenic content, and that in the form of pentoxide, practically insoluble in water, fairly stable under New England weather conditions, and may be applied to most plants

with little danger of injury. It is a slow-acting poison but effective: the fineness of particles and light flocculent character insure a high power of suspension and uniform distribution; the white mixture readily indicates the leaf surface covered, and dries to a film which adheres with great persistence.

(2) *Calcium Arsenate.*

Arsenate of lime was employed as an insecticide about 1912, or possibly earlier. Dry arsenate of lime appears to have been first prepared commercially by Riches, Piver & Co. of New York. The late war, with resulting high prices, brought the product into prominence.

As with lead arsenate there are three separate products to be considered, as follows: —

1. Acid calcium arsenate, $CaHAsO_4H_2O$.
2. Neutral calcium arsenate, $Ca_3(AsO_4)_22H_2O$.
3. Basic calcium arsenate, a product of rather variable composition, probably depending on the amount of excess lime. This is the commercial article sold under the name of calcium arsenate.

Composition. — The composition of theoretical acid and neutral calcium arsenates, and of a commercial basic calcium arsenate, is substantially as follows: —

	Acid Calcium Arsenate (Per Cent).		Neutral Calcium Arsenate (Per Cent).		Commercial Basic Calcium Arsenate (Per Cent).	
Calcium oxide (CaO),		28.310		38.744		44.128
Arsenic pentoxide (As_2O_5),		58.045		52.957		45.238
Equivalent to metallic arsenic (As) (per cent).	37.848		34.531		29.497	
Ratio As_2O_5 : CaO,	1 : 0.488		1 : 0.732		1 : 0.975	
Water of combination,		13.645		8.299		10.634
		100.000		100.000		100.000

Physical Properties. — The calcium arsenates are soft, white powders of fine particles with a good power of suspension and adhesiveness. The specific gravity (15) of a pure acid salt at 20/4° C. was 3.09, and of a neutral salt, 3.23. The commercial dry basic calcium arsenate is a bulky, impalpable powder of 80 to 100 cubic inches to the pound.

Stability. — The acid salt is largely soluble in water, and the neutral salt appreciably so, as determined by the Hilgard method. Carbonic acid will decompose both salts with the formation of carbonate and the liberation of arsenic. Dilute solution of alkalies and their salts will increase the solubility of the arsenic, the acid salt invariably proving the more unstable. For these several reasons calcium arsenate used alone burns foliage very badly. As in the case of other arsenicals, milk of lime prevents burning by combining with any soluble arsenic which may be formed.

The basic products are more stable than the acid or neutral salts, due evidently to the higher content of lime.

The status of the dry commercial products is still rather indefinite. Carbonate of lime is present in some instances as an impurity or filler, having neither toxic nor protective action.

Form of Guaranty. — Calcium arsenate is usually sold under the following form of guaranty: —

		Per Cent.
Active ingredients: —		
Tricalcium arsenate, not less than		76.00
Total arsenic pentoxide, not less than	42.50	
Total arsenic (as metallic), not less than	28.00	
Inert ingredients, not more than		24.00
		100.00

Water Soluble.

Soluble arsenic pentoxide, not more than	1.50
Soluble arsenic (as metallic), not more than	1.00

The remarks relative to the form of guaranty of lead arsenate hold equally well for the form of guaranty of calcium arsenate. Note particularly that the killing power of calcium arsenate is apparently greater than that of lead arsenate on account of the higher percentage of arsenic pentoxide. Therefore a smaller quantity is used in the spray, so as to give the same amount of metallic arsenic as when arsenate of lead is used.

To summarize: Both acid and neutral calcium arsenates are of relatively high arsenic content, but too soluble to warrant their use without excess lime. The basic product is of a lower arsenic content but more stable. They are effective poisons, the fineness of particles and light flocculent character insuring a fair power of suspension and uniform distribution. The white mixture indicates the leaf surface covered, and dries to a film that is persistent under average weather conditions; and is, in brief, an efficient and reasonably satisfactory arsenical for the more resistant plants.

Standard Formulas for Application.

As previously mentioned, there is a great difference in the rapidity of killing power between arsenates and arsenites. For this reason the two classes of materials cannot be compared on the basis of arsenic contained. The following table represents basic quantities of the several materials of standard or near standard composition which may be used. Naturally the amounts to be used must be varied to adapt the spray to different kinds of insects, and to make it safe when used on different kinds of plants.

Arsenical.	Composition of Arsenical.		Amount of Arsenical in Spray.		Pounds of Metallic Arsenic per Barrel of Spray.
	Arsenic Oxides (Per Cent).	Equivalent in Metallic Arsenic (Per Cent).	Per Barrel (50 Gallons) (Pounds).	Per Gallon (Ounces).	
Arsenites: —					
Paris green, . . .	50.00 (As_2O_3)	37.87	0.333	1/10	0.126
Arsenates: —					
Dry acid lead arsenate, .	30.00 (As_2O_5)	19.56	1.5	1/2	0.3—
Dry basic calcium arsenate,	40.00 (As_2O_5)	26.08	1.0	1/3	0.3—

Any arsenite of known composition may be applied in quantity to furnish metallic arsenic equal to that in an application of Paris green; whereas any arsenate of known composition may be applied to furnish metallic arsenic equivalent in amount to that used in arsenate of lead.

For most farm and orchard crops it is unwise to use any arsenical without protecting the plant against foliage damage. The addition of milk of lime affords protection against this arsenical injury. Four pounds of high-grade quicklime (95 per cent CaO) are generally sufficient for 50 gallons (1 barrel) of spray. The lime should be slaked carefully, sieved, diluted to nearly 50 gallons, and the arsenical added slowly with thorough agitation *immediately* before application.

Arsenical Injury.

It is evident from what has been stated repeatedly that the carbonic acid and ammonia of the atmosphere in conjunction with dews, fogs or light rains and high temperatures will materially increase the amount of soluble arsenic. When the arsenic is in solution in the spray liquid, or drops of rain or dew on the foliage, some of it is absorbed by the tissues of the leaf. A very minute amount of absorbed arsenic may have no injurious effect on the cell; but if, on account of a high soluble arsenic content of the spray material, or too long standing of the liquid before drying, a sufficient amount has been absorbed, the tissue is killed. Two types of injury are distinguished (16), — *acute* poisoning and *chronic* poisoning.

In cases of *acute poisoning* the leaf, or large areas of it, turns black within twenty-four hours after the application; or sometimes, when the insecticide has dried rapidly after application, the blackening may appear after the first period when water has stood on the foliage for some time. In *chronic poisoning* there are no definite lesions on the leaves, but after two or three weeks they prematurely turn yellow and drop off. Apparently in this type of poisoning not enough arsenic is absorbed to kill the cells outright, but yet enough to interfere with and finally stop the functioning of the cells.

Certain deductions seem warranted. Conditions favoring a rapid drying of the arsenical and its continuance in a dry state are propitious.

For instance, a relatively high temperature, low humidity and a good circulation of air at the time of application, followed by warm, dry weather should tend toward a minimum of arsenical injury. On the other hand, factors conducive to solubility of the arsenic and its passage by osmosis into the substance of the leaf are detrimental, as, for example, warm, "muggy" weather, or warm weather accompanied by fogs or heavy dews. Rains are not necessarily injurious if of sufficient quantity to wash off the soluble arsenic as soon as it is formed.

2. Hellebore.

White hellebore is the powdered rhizome (root) of *Veratrum album*, and green or American hellebore that of *V. viride*. Both are sold as insecticides in the form of a gray powder containing about 1 per cent of alkaloids (usually guaranteed from 0.30 to 0.42 per cent) and a varying amount of ash. Though known to possess poisonous properties, hellebore received little attention until about 1842 in England (17), and 1865 in this country (18).

The chief insecticidal action of hellebore is as a stomach poison. It appears to possess also a certain value as a repellent. The active principles which give hellebore its insecticidal value are certain alkaloids which are poisonous to insects, but in amounts usually recommended for use do not seriously affect man. These alkaloids are so volatile that the material soon loses its strength and efficiency, particularly if exposed to the air. Consequently a fresh product should always be demanded. Its non-poisonous effect on man renders hellebore a suitable material for the protection against chewing insects of fruits or vegetables that are about to ripen or are soon to be eaten. It is, however, limited to rather small-scale applications, the cost of the material prohibiting its use on large areas. The material may be applied either dry or as a spray. In dry form it is used either undiluted or mixed with five times its volume of flour or finely divided air-slaked lime. For liquid application its use at the rate of $\frac{1}{2}$ ounce to 1 gallon of water is recommended.

II. CONTACT POISONS FOR SUCKING INSECTS.

Contact poisons include a large number of diversified compounds (solid, liquid and gaseous), and their effectiveness may depend upon more than one property. The compound may act in any of the following ways: —

1. Glue the insect down.
2. Attack the body, dissolving fat and even muscle, precipitating proteids, etc.
3. Act as a narcotic, paralyzant or anæsthetic.
4. Asphyxiate the insect by closing the breathing pores (spiracles or tracheæ), or, by saturating the body, prevent necessary aeration.

These indicate some of the possibilities, but the principal action and the contributory are generally difficult to define. These poisons are generally soluble or emulsified products. They kill only by contact. Liberal and thorough application is necessary to assure effectiveness, and drench spraying is usually employed. The weaker the surface tension of the spray and the thinner the chitin of the insect the more rapid the penetration.

The contact poisons that will be considered are (1) soaps, (2) sulfur sprays, (3) oil sprays, (4) nicotine, and (5) pyrethrum.

1. Soaps.

There are four different types of soap sprays, as follows: —

1. Whale-oil or fish-oil soaps.
2. Laundry soap.
3. Rosin fish-oil soap, soap "stickers."
4. Fish-oil soaps and nicotine.

(1) *Whale-oil or Fish-oil Soaps.*

Whale-oil soap was first brought forward in 1842 by the experiments of Haggerston (19), and showed an efficiency which it has steadily maintained up to the present. It is interesting to note that many of the statements made at that time in regard to its value have proved true through years of subsequent use, and the dosage first recommended is practically the same as that used to-day.

At the present time soaps made from fish oil have largely supplanted the true whale-oil soaps, but the similarity in the nature and effectiveness of the two materials has led to the habit of using these two names more or less interchangeably. Strictly speaking, however, the commercial product to-day is largely made from various fish oils.

For use as a summer spray against plant lice and other soft-bodied insects, as well as younger stages of more resistant types, it is very effective when applied at the rate of 1 pound to 6–8 gallons of water, according to the tenderness of the plant in question. It has sometimes been used for dormant treatment of scale insects at the rate of 2 pounds to 1 gallon of water, and applied while hot. The stronger, more efficient sulfur sprays have largely supplanted it for this purpose.

(2) *Laundry Soap.*

In the absence of whale-oil or fish-oil soaps, common laundry soap may be employed effectively for the same type of insects. An average soap of this type should be used at the rate of 1 pound to 2–4 gallons of water, depending on the resistance of the insects treated.

(3) *Rosin Fish-oil Soap, Soap "Stickers."*

On plants having a smooth and waxy foliage, such as cabbage and similar types, lead arsenate and Bordeaux mixture will not adhere at all well unless used with some kind of soap as a "sticker." Types of resinous soaps have come into use under the general name "Resin (Rosin) Fish Oil Soaps," and are especially adapted for such purposes. These are recommended to be used at the rate of 3–4 pounds to 50 gallons of spray (or about 1 ounce to 1 gallon), and to be added to the diluted spray material immediately before it is to be applied. In the preparation of this type of soap for a spray it is necessary to add the water a little at a time, stirring vigorously all the while, until the soap has entirely dissolved; otherwise the resinous nature of the material repels the water, making a solution almost impossible.

Except on the particular types of plants just mentioned (cabbage and similar plants), soap should not be used with arsenicals or Bordeaux mixture. Arsenicals are unstable in the presence of the alkali of the soap, with the consequent danger of the formation of soluble arsenic (20). In this particular case, however, the application is made so soon after the soap is added that there is little opportunity for breakdown; and, further, the waxy leaves seem to offer more resistance to arsenical injury than would foliage of ordinary texture. The alkalies entering into the composition of our common soaps are mainly compounds of sodium and potassium. Such soaps are the only ones soluble in water. When, however, soap is combined with Bordeaux mixture or lime-sulfur sprays, calcium soaps are formed which are insoluble in water, making a gummy, sticky mass which is apt to clog the spray apparatus. Moreover, other products of this breakdown are formed which are either actively dangerous to the plant or are of no use whatever as an insecticide.

(4) *Fish-oil Soaps and Nicotine.*

Commercial brands of fish-oil soaps combined with a small amount of nicotine are on the market and appear to have a considerable sale. These are rather expensive, and usually their nicotine content is quite low, so that in general, better satisfaction can be obtained by combining soap and nicotine solutions as needed. (See Nicotine Sprays, page 20.)

2. Sulfur Sprays.

These are efficient contact poisons for certain scale insects, and possess substantial fungicidal value as well. They are supplanting the miscible oils, probably due in large measure to the deleterious after-effects of the latter. Concentrated lime-sulfur solution, dry lime-sulfur, barium tetrasulfide (B. T. S.), and sodium polysulfide, or so-called soluble sulfur, will be considered. All of these materials seem to have the following properties in common: —

1. The amount of polysulfide sulfur present largely governs the effectiveness of the material.

2. Thiosulfate sulfur is a product of the breaking down of polysulfide as well as an original constituent of the product, and hence is present in variable amounts.

3. The free sulfur contained is usually inert as an insecticide. It does, however, have a distinct fungicidal value. (See page 26.)

(1) *Lime-sulfur.*

The efficiency of lime-sulfur-salt wash (21) for the San José scale appears to have been first demonstrated by F. Dusey of Fresno, Cal., in 1886, using a sheep dip prepared by A. T. Covell. The dip (22, 23), however, seems to have been of Australian origin. About the year 1900 it began to be used in the eastern States for the control of the San José scale.

The formulas adopted by different experiment stations showed appreciable variations. A proportion of 1 pound of lime and 2–2¼ pounds of sulfur to 1–1⅗ gallons of water assures solution of the largest proportions of lime and sulfur, the smallest amount of sludge or sediment, and a high proportion of calcium polysulfide (particularly pentasulfide) with a moderate amount of calcium thiosulfate, thus making the most efficient product with the least waste. The lime must be a high-grade caustic, substantially free from magnesia, which causes unnecessary loss of sulfur as hydrogen sulfide and increases the amount of sediment. A greater proportion of lime causes the formation of more thiosulfate, and favors the formation of crystals of oxysulfide. Boiling for thirty to sixty minutes with proper agitation should be sufficient to dissolve all of the sulfur; longer heating is detrimental. The resulting solution should be about 24° or 25° Baumé. A greater concentration is generally obtained at a sacrifice of thiosulfate, which is converted into sulfite and free sulfur which being insoluble increase the amount of sediment.

The commercial product has largely superseded the home-made except, possibly, in the case of orchard practice on a large scale. Lime-sulfur solution appears to have been first produced commercially by the Rex Spray Company (formerly Rex Stock Food Company) of Omaha, Neb., as a sheep and cattle dip, which was approved by the Bureau of Animal Industry Sept. 30, 1903. Later the product was tested as a spray at Corvallis, Ore., and largely marketed as such. The commercial concentrate is to-day practically standardized on a 33° Baumé basis. A product of greater density is more likely to crystallize on chilling.

Concentrated lime-sulfur properly prepared is a clear orange-red solution with more or less sludge, depending on the purity of the lime and sulfur, formula, and method of treatment. The clear solution consists chiefly of so-called calcium polysulfide and calcium thiosulfate in varying amounts. The sludge may contain free sulfur, together with calcium sulfite, calcium sulfate and impurities from the lime. The polysulfide is a combination of lime and sulfur, approximating a ratio of 1 : 5, or CaS_5; the thiosulfate is CaS_2O_3.

Composition. — A comparison of home-made concentrate and the commercial 33° Baumé concentrate is shown in the following table: —

	Home-made (24½° B.) (Per Cent).		Commercial (33° B.) (Per Cent).	
Water,		75.00		68.04
Sulfur in solution,		17.00		24.75[1]
Polysulfide sulfur,	13.75		24.00	
Thiosulfate sulfur,	3.25		.75	
Ratio thiosulfate sulfur to polysulfide sulfur,	1:4.23		1:32.00	
Calcium,		5.57		6.65
Oxygen in combination,		2.43		.56
		100.00		100.00
Water,	75.00		68.04	
Calcium polysulfide ($CaS_{4.85}$)	17.29		30.18	
Calcium thiosulfate,	7.71		1.78	
	100.00		100.00	

[1] A conservative estimate.

Stability. — Lime-sulfur is readily oxidized on exposure to air, the polysulfide being converted into thiosulfate with precipitation of sulfur, the thiosulfate into sulfite with precipitation of additional sulfur, and the sulfite into sulfate, as follows: —

$$CaS_5 + O_3 = CaS_2O_3 + S_3$$
$$CaS_2O_3 = CaSO_3 + S$$
$$CaSO_3 + O = CaSO_4$$

This necessitates full containers, well-stoppered, or a thin covering of paraffin oil to prevent decomposition of lime-sulfur in storage.

The guaranty of commercial concentrates is generally about 33° Baumé and 25 per cent sulfur in solution. The efficiency, however, is more accurately measured by the amount of polysulfide sulfur in solution, irrespective of whether the effectiveness is a result of direct action or from products of decomposition. The total sulfur in solution apparently gives the home-made product, containing a much larger proportion of thiosulfate sulfur, relatively too high a rating.

According to P. J. Parrott, of the New York (Geneva) Agricultural Experiment Station, a gallon of diluted lime-sulfur for dormant spray (San José scale) should contain about 0.297 pound of sulfur in solution, or 3.45 per cent; and for fungicidal work on foliage, 0.065 pound of sulfur, or 0.775 per cent. The following formulas are so calculated for concentrates of 15° to 36° Baumé: —

Table I. — *Standard Formula for Application (24).*

Density of Solution, Baumé Degrees.	Equivalent in Specific Gravity.	Sulfur Equal to 1° B. (Per Cent).	Weight of 1 Gallon of Concentrate (Pounds).	Sulfur in 1 Gallon of Concentrate (Pounds).	Sulfur in Solution (Per Cent).	Dilution for San José Scale:[1] To 1 Gallon of Concentrate add Gallons of Water.	**Dilution for San José Scale:[1] For 50 Gallons of Spray use Gallons of Concentrate.**	Dilution for Summer Spray:[2] To 1 Gallon of Concentrate add Gallons of Water.	**Dilution for Summer Spray:[2] For 50 Gallons of Spray use Gallons of Concentrate.**
36	1.3303	0.75	11.08	2.99	27.00	9	**5**	45	**1**
35	1.3182	.75	10.98	2.88	26.25	8¾	**5¼**	43¼	**1¼**
34	1.3063	.75	10.88	2.77	25.50	8¼	**5¼**	41½	**1¼**
33	**1.2946**	**.75**	**10.78**	**2.67**	**24.75**	**8**	**5½**	**40**	**1¼**
32	1.2832	.74	10.69	2.53	23.70	7½	**5¾**	37¾	**1¼**
31	1.2719	.74	10.60	2.43	22.95	7¼	**6**	36¼	**1¼**
30	1.2609	.73	10.51	2.30	21.90	6¾	**6½**	34¼	**1½**
29	1.2500	.73	10.42	2.20	21.15	6½	**6¾**	32¾	**1½**
28	1.2393	.72	10.32	2.08	20.15	6	**7¼**	31	**1½**
27	1.2288	.72	10.23	1.99	19.45	5¾	**7½**	29½	**1½**
26	1.2185	.71	10.15	1.87	18.45	5¼	**8**	27¾	**1¾**
25	1.2083	.70	10.07	1.76	17.50	5	**8½**	26	**1¾**
24	1.1983	.69	9.98	1.65	16.65	4½	**9**	24¼	**2**
23	1.1885	.68	9.90	1.55	15.65	4¼	**9½**	22¾	**2**
22	1.1789	.67	9.82	1.45	14.75	3¾	**10¼**	21¼	**2¼**
21	1.1694	.66	9.74	1.35	13.85	3½	**11**	19¾	**2½**
20	1.1600	.65	9.67	1.26	13.00	3¼	**11¾**	18¼	**2½**
19	1.1508	.65	9.59	1.18	12.35	3	**12½**	17	**2¾**
18	1.1417	.65	9.51	1.11	11.70	2¾	**13½**	16	**3**
17	1.1328	.65	9.44	1.04	11.05	2½	**14¼**	15	**3¼**
16	1.1240	.65	9.37	0.97	10.40	2¼	**15¼**	14	**3¼**
15	1.1154	.65	9.30	0.90	9.75	2	**16½**	12¾	**3½**

[1] Density of spray, 4.6° Baumé, or 1.0327 specific gravity.
[2] Density of spray, 1.0° Baumé, or 1.0072 specific gravity.

(2) *Dry Lime-sulfur.*

Dry lime-sulfur was first marketed in 1915 by the Sherwin-Williams Company of Cleveland, Ohio. The use of the dry product effects a material saving in cost of containers, transportation, storage and possible leakage. Commercial lime-sulfur solution contains nearly 68 per cent of water, while the dry product usually contains only a small amount of uncombined water. In the production of dry lime-sulfur the polysulfide apparently undergoes partial decomposition, and a portion of the sulfur formerly

combined with the lime splits off and fails to redissolve on the addition of water, and is termed free sulfur.

Composition. — Dry lime-sulfur is usually guaranteed about as follows: —

		Per Cent.
Active ingredients,		80.00
Calcium polysulfide,	63.00	
Calcium thiosulfate,	5.00	
Free sulfur,	12.00	
Inert ingredients,		20.00
		100.00

A 33° Baumé lime-sulfur solution containing 24.75 per cent sulfur, concentrated to a like basis, should contain substantially 61.95 per cent total sulfur. If 12 per cent was rendered insoluble by evaporation, 49.95 per cent remains soluble. Five per cent calcium thiosulfate is equivalent to 2.11 per cent thiosulfate sulfur, which deducted from the soluble sulfur leaves 47.84 per cent polysulfide sulfur.

(3) *Barium Tetrasulfide.*

Barium tetrasulfide (25) or B. T. S. was prepared experimentally as an insecticide by the Thomsen Chemical Company of Baltimore, Md., in 1913. The product is guaranteed as follows: —

		Per Cent.
Active ingredients,		82.00
Barium tetrasulfide (BaS_4),	68.00	
Barium thiosulfate,	6.00	
Free sulfur,	8.00	
Inert ingredients,		18.00
		100.00

Barium tetrasulfide is a fairly satisfactory contact poison, yet it possesses no distinct advantages over lime-sulfur preparations. It has never replaced lime-sulfur to any great extent, and is not now widely used, largely because it is more expensive.

(4) *Soluble Sulfur.*

Soluble sulfur or sodium polysulfide was first marketed by the Niagara Sprayer Company of Middleport, N. Y., about 1912. Con-sol, a sodium sulfur compound, prepared by the American Horticultural Distributing Company of Martinsburg, W. Va., was offered about 1905, but little information has been received relative to the nature of the product.

Soluble sulfur is guaranteed as follows: —

		Per Cent.
Active ingredients,		85.00
Sodium polysulfide (Na_2S_4),	56.00	
Sodium thiosulfate,	25.00	
Free sulfur,	4.00	
Inert ingredients,		15.00
		100.00

Soluble sulfur is used considerably as a dormant spray, and is fairly satisfactory. It is exceedingly dangerous as a foliage spray unless an excess of lime is added. It has no marked superiority over lime-sulfur preparations, and has not supplanted them to any great degree.

Formulas for Application.

These various materials may all of them be applied in such quantities as to furnish approximately equivalent amounts of soluble sulfur. That this basis is not entirely sound is shown by the fact of difference in the ratio between polysulfide sulfur and thiosulfate sulfur. This difference should, of course, be considered when computing amounts of spray materials needed. On the basis of amounts of soluble sulfur equal to the standard application of 33° Baumé lime-sulfur concentrate (1–8 for dormant spray and 1–40 for summer spray), the following table is presented as showing suggested formulas for application: —

Material.	Soluble Sulfur (Per Cent).	Amount of Material in 50 Gallons of —			
		Dormant Spray.		Summer Spray.	
		Gallons.	Pounds.	Gallons.	Pounds.
Lime-sulfur concentrate,	24.75	5.556	$59\frac{3}{4}$	1.22	13
Dry lime-sulfur,	50.00	–	$29\frac{1}{2}$[1]	–	$6\frac{1}{2}$
Barium tetrasulfide,	41.00	–	36[1]	–	8
Soluble sulfur,	51.35	–	$28\frac{3}{4}$[1]	–[2]	–[2]

[1] These amounts are greater than are recommended by the manufacturers.

[2] Soluble sulfur should never be used as a summer spray, save with a great excess of lime.

3. Oil Sprays.

Oil sprays owe their insecticidal value chiefly to their asphyxiating effect. To a certain degree some of them may also have corrosive effect. Oil sprays likewise have a peculiar creeping power which enables the operator to cover the tree area even under unfavorable conditions. With most other contact insecticides, an insect to be killed must be actually "hit." These oils will be considered under two divisions: (1) emulsions, and (2) miscible oils.

(1) *Emulsions.*

The idea of combining soap, kerosene and water to form a stable mixture which could be safely applied to foliage undoubtedly occurred to growers very early. The first record of successful accomplishment, however, was in 1870 (26). Cook (27) records the attaining of a successful emulsion in experiments in 1877–78, and the formulas which he developed, bearing his name, were used for many years. The experiments of Riley and Hubbard, covering a number of years, carried forward this idea of a permanent mixture of kerosene and soap, and finally led to the production of the formula (28) which is used practically unchanged at the present day. This formula is as follows: —

Kerosene,	2 gallons
Water (soft),	1 gallon
Soap,	½ pound

The soap is dissolved in boiling water, and while the mixture is still hot the kerosene is added. The mixture is then churned, with a bucket pump with nozzle turned back into the liquid, until it has reached the consistency of a thick cream. Upon cooling, this thickens still further, and if properly made no free oil should separate out on the surface. This stock emulsion should last for some time, but it is much better to make it up only as needed. Where the water is hard it must be softened by the addition of borax or soda to prevent the lime or magnesium present from combining with the soap, which makes impossible an emulsion with the oil.

For spraying, dilute with 9–10 parts of water for aphids or other soft-bodied insects. Greater strengths are sometimes recommended for more resistant insects, or on trees when dormant.

Kerosene emulsion cannot be used safely in combination with other sprays (lead arsenate, lime-sulfur, etc.) owing to the breakdown of these materials in the presence of the soap, and the consequent liberation of free oil as well as other products of this double decomposition, which are dangerous to plants. This spray has now been largely superseded by the various nicotine solutions which have proved fully as efficient, are more easily prepared, can be used with safety to foliage, and, moreover, can be used in combination with other sprays, thus saving the trouble and expense of separate applications.

Carbolic Acid Emulsion. — This is a fairly effective remedy for certain root-feeding insects, such as root maggots of onion, cabbage and turnip. Its value for other purposes is somewhat limited. It is made as follows: —

Soap,	1 pound
Water,	1 gallon
Crude carbolic acid,	1 pint

This is prepared in the same way as is kerosene emulsion. It will not, however, attain the same curd-like consistency on standing as will kerosene

emulsion, but remains in a more or less fluid condition. It should be diluted 1 part to 25–30 of water, and applied to the ground around the stems. Its use is restricted to small areas.

(2) *Miscible Oils.*

Miscible oils are formed from a mineral oil emulsified with a vegetable oil, with some alkali present. A stable stock emulsion is formed which mixes readily with water. These preparations are particularly adapted for use on old, rough-barked trees heavily encrusted with scale, as the oils spread over the bark more readily than do sulfur sprays. As the proportion of component parts is seldom furnished, and the manufacture of these oils is, in fact, more or less of a trade secret, the directions furnished by the manufacturer, both as to dilution and application, should be very carefully followed, whatever brand is used. In general, for dormant spraying these oils are diluted at the rate of 1 part to 12–15 parts of water.

The use of these oils has sometimes been followed by distinct injury, even where proper precautions have been taken and directions carefully followed. There are also reports of cumulative injury following repeated applications (29).

Miscible oils are relatively expensive dormant sprays in spite of the fact that the oil is said to go further in application than an equal amount of lime-sulfur. The uncertainty of the exact effect of the oils upon the health of the tree seems to favor the use of lime-sulfur, which has proved to be an efficient scale destroyer and can be used with safety.

4. Nicotine.

The value of tobacco in killing soft-bodied types of insects was discovered very early. In 1763 it was recommended in France for the control of plant lice, both tobacco powder and a water solution being applied. Its use in America was first recorded in 1814. Its effectiveness against soft-bodied insects and its safety to foliage of plants soon gave it a prominence which has continued undiminished to the present day. The most active principle of tobacco, and the one which gives it its value as an insecticide, is the alkaloid, nicotine. Soluble in water, entirely volatile, this is one of the most virulent poisons known.

(1) *Nicotine Sulfate.*

At the present time there are on the market a number of different commercial brands of nicotine, of various grades and strengths, which have to a large extent superseded the home-made preparations for general use. For garden and orchard operations the highly concentrated product containing 40 per cent of nicotine in the form of nicotine sulfate is at present extensively used. This is sold under various trade names, as "Black-Leaf 40," "Nicotine Sulfate 40%," etc. It has proved especially valuable for the control of many soft-bodied sucking insects. It can be

applied at strengths required for efficient insect control without injury to foliage, and, moreover, it can be combined with other standard sprays (lime-sulfur, lead arsenate, etc.) without impairing either their efficiency or its own.

The amount of dilution recommended varies according to the resistance of the insects for the control of which it is applied. When used at a dilution of $\frac{3}{8}$–$\frac{1}{2}$ pint in 50 gallons of water (or, where only a few plants are to be treated, 1–1$\frac{1}{2}$ teaspoonfuls to 1 gallon of water), nicotine sulfate is efficient for the control of the average soft-bodied sucking insects of orchard and garden. When nicotine sprays are used alone in water, the addition of soap, 2–4 pounds to every 50 gallons of spray ($\frac{2}{3}$–1 ounce to 1 gallon), increases their spreading power and general effectiveness. Without soap the nicotine solutions show a tendency to form into drops which roll off the leaves without penetrating to and thoroughly wetting the insects. When nicotine sprays are used in combination with other insecticides the soap should *never* be added, owing to the breakdown of these chemicals in the presence of the strong alkali of the soap, with the consequent formation of compounds dangerous to foliage. (See page 12.)

Recent studies upon the effects of nicotine as an insecticide (30) have shown that, regardless of the form in which it is employed, the killing action is by paralysis, through the penetration of the nicotine vapors into the body of the insect. The effectiveness of nicotine sprays, therefore, depends on the amount of nicotine released. The experiments of Graham and Moore (31) have indicated that nicotine sulfate alone is nonvolatile, but if a solution of this material is treated with soap to render it alkaline, nicotine is at once released. Inasmuch, therefore, as the vapor of nicotine is the principal cause of the death of insects sprayed with tobacco solutions, the maximum efficiency of solutions containing nicotine sulfate can only be obtained by insuring that the spray is rendered alkaline. This is best attained by the addition of soap.

Within the last few years nicotine sulfate has been used, with lime and kaolin as carriers, in a dust application for the control of the walnut aphis and various truck crop insect pests, in California. In this form it has demonstrated a killing efficiency and rapidity of action superior to the spray applications. Furthermore, it can be applied faster and costs less than when applied in liquid form. So far as known, this has not as yet been used in Massachusetts. Its convenience of application and rather remarkable success as far as tried make it a promising form of application, especially in market gardens.

5. Pyrethrum.

Pyrethrum, Persian or Dalmatian insect powder, is the powdered flowers of *Chrysanthemum cinerariæfolium;* and Buhach, the California product, the powdered flowers of *C. coccineum*. The bright yellow powder owes its insecticidal value to the presence of certain volatile oils, contained in the flower heads, which are quite poisonous to insects, but apparently harmless

to man. The material rapidly loses its effectiveness unless carefully stored in tight receptacles.

Pyrethrum is quite effective on soft-bodied insects and larvæ not protected by hairs, and is especially useful against young cabbage worms on cabbage and cauliflower plants which are soon to be harvested. It acts purely as a contact insecticide; the application must be made very thoroughly, therefore, to bring the material in actual contact with the insects to be treated. Its action is of short duration, the active principles being so volatile, and if used too sparingly some of the insects are merely numbed and eventually recover. Its usefulness is consequently very limited. It is rather costly, and is apt to vary as to purity.

Pyrethrum may be applied as a dry powder, pure or diluted with two to three times its bulk of flour, air-slaked lime, etc., which increases its adhesiveness. When diluted with any carrier it is well to keep the mixture in some tightly closed receptacle for twenty-four hours before using. It can also be applied as a spray at the rate of 1 ounce to 2 gallons of water, which should stand for twenty-four hours before using. For immediate use a decoction can be made by extracting in a quart of boiling water for from five to ten minutes, then adding the rest of the water.

B. FUNGICIDES.

Fungicides, as the term is applied in this bulletin, are substances used to kill or prevent the growth of fungi. They are applied to the host as spray, dust or fumes. For the most part, they are used as preventives and not cures, and therefore should be applied before the fungus is present on the surface of the host plant. As such, they protect by forming a poison barrier through which the threatening fungus cannot penetrate. Sometimes, however, they are used to destroy a pathogen (parasitic organism which causes the disease) which is already present; *e.g.*, powdery mildews and potato tuber organisms, in which case they are called disinfectants. In respect to use, then, we distinguish the two groups of fungicides: (I) Protective sprays or dusts, and (II) Disinfectants. In some cases, however, the same substance may be used for both purposes.

A good fungicide must have the following qualifications: —

1. It must kill or inhibit the growth of the pathogen at the concentration used.
2. It must not seriously injure the host plant at this same concentration.
3. If used as a spray it must adhere tenaciously to the surface of the host.
4. If used as a protective spray it must be practically insoluble in water after it dries on the host, but still go very gradually into solution under the influence of atmospheric conditions, host or pathogen.
5. It must be reasonably low in cost, both of material and of labor of application.

Most of the fungicides which are in general use owe their effectiveness to the presence in some form of one of three elements, — copper, sulfur or mercury. Formaldehyde, effective on account of its reducing qualities, is an exception. On this basis we shall divide them for convenience of discussion, as follows: —

I. PROTECTIVE APPLICATIONS.

1. Copper Fungicides.

This group of fungicides owes its effectiveness to the action of dissolved copper on the fungus. *Copper sulfate* was perhaps the first to come into general use. Its use for disinfection of smutted grain seed was perfected during the eighteenth century, and it is still used for that purpose in Europe and Australia.

Numerous *copper ammonia washes* have also been used with more or less success, mostly for the diseases of ornamental plants. The best known and most widely used of these washes are Eau celeste (cuprammonium sulfate) and ammoniacal copper carbonate. Since none of them has come into general use for farm or orchard crops, they need not be discussed further at this time.

The most popular and most extensively used of all copper fungicides is Bordeaux mixture. Home-made Bordeaux and commercial Bordeaux preparations are discussed separately below. Other copper fungicides have not been used enough to warrant separate discussion at this time.

(1) *Bordeaux Mixture.*

A thick paste made by mixing slaked lime with copper sulfate and applied to the grapevines of southern France for the purpose of warding off pilfering vagrants was the origin of Bordeaux mixture. Millardet, a professor of botany at Bordeaux, observed that the vines which were so treated suffered less from the downy mildew (*Plasmopora viticola*), which had been introduced from America into France about 1878. He began investigations, the results of which were published from 1882–85, and gave to the world its most widely used fungicide. The whole science of protective spraying began with his work. Soon after the effectiveness of Bordeaux mixture in controlling grape mildew had been demonstrated it was used with equal success for potato mildew and black rot of grape. In 1887 it was introduced into the United States by the United States Department of Agriculture, and its use extended to other diseases, until by the end of the century it had come to be regarded almost as a panacea for all fungous diseases of plants.

Formulas. — Bordeaux mixture as now used is still made from lime, copper sulfate (blue vitriol or bluestone) and water, but many different formulas for the proportions of the three ingredients have been proposed and used with success for various diseases. For Massachusetts crops and conditions the "4–4–50 formula" (4 pounds copper sulfate, 4 pounds quicklime and 50 gallons of water) is preferred, except in the case of the late sprays for potatoes and the spray for celery and grapes. In the latter cases 5–5–50 is recommended. Other formulas sometimes employed are 3–3–50, 5–4–50 and 6–4–50.

Chemical and Physical Properties. — When the dissolved copper sulfate and milk of lime are poured together, a reaction takes place between them resulting in the formation of a voluminous, gelatinous colloidal precipitate which does not settle rapidly to the bottom, but remains evenly distributed throughout the liquid and begins to settle only after standing undisturbed for several hours. As seen under the microscope it is a mass of very thin precipitation membranes, each in the form of a minute closed bag. After a few hours the gelatinous precipitate gradually becomes crystalline, the copper salt then appearing in the form of blue sphærocrystals (32) which do not remain afloat but settle to the bottom. In the best mixtures these membranes are most fully and abundantly formed, and as a result they "stand up" longest. In poor mixtures they settle to the bottom quickly. The ability of the mixture to perfectly cover the surface of the plant and to adhere tenaciously is dependent on the thoroughness of development of these precipitation membranes. It is therefore customary to gauge the excellency of the mixture to no inconsiderable extent by the length of time required for the precipitate to settle. Since even the best of mixtures will begin to settle after a few hours, it is essential that, to get the best results, Bordeaux be applied when freshly prepared. In the 4–4–50 Bordeaux there is a considerable excess of lime (as calcium hydroxide). When the spray dries on the leaves, the membranes which are spread over the surface conform tightly to every irregularity, much as a piece of thin wet tissue paper does when dried on a flat surface, and are not washed away readily by rains or removed by winds or other agencies. Bordeaux mixture surpasses all other fungicides in its ability to adhere to the host. Copper, its only active fungicidal agent, is in these dry membranes in a form almost insoluble in pure water. Since it cannot affect the fungus in an insoluble form, it must be brought into solution by some other agency. The following agencies have been found more or less active in this direction: —

1. Carbon dioxide from the air or from the plant, in solution in dew or rain drops, very gradually brings the copper into solution after the excess lime has been carbonated.
2. Ammonia and nitrous or nitric acids, present in small amounts in rain water, cause some solution of the copper.
3. Organic substances such as sugars, excreted in small quantities from the host cells, bring about very gradual solution.
4. There is some evidence that excretions from the fungus itself bring into solution enough copper to kill it.

Bordeaux Injury. — Bordeaux mixture falls short of the requirements of a good fungicide in that it frequently causes injury to the plant. The copper, brought into a soluble form in one or more of the ways enumerated above, enters the tissues of the plant directly through the epidermal walls by a process of osmosis, or through the stomates, lenticels or wounds. The invaded cells are killed by the toxic copper. On leaves this results in definite dead spots or irregular areas on margins or tips. More or less defoliation may result on fruit trees. On fruits, the death of some of the

cells incites the production of protective cork cells, thus causing the rough russet areas which disfigure the surface of fruits such as apples or grapes. The extent of the injury varies with the hosts, being most severe on peaches and plums, and less so on apples, grapes and potatoes, but varying even here with the variety, weather conditions, stage of development and many other factors. No host seems to be immune under all conditions. Apparently, continued rainy weather increases injury. According to Hedrick (33) it is not prevented by the use of excess lime. The apple growers of Nova Scotia, however, use an excess lime Bordeaux, 3-10-50, which is found to be effective against scab, while it greatly reduces the russeting of fruit which results from use of the ordinary Bordeaux formula.

(2) *Commercial Bordeaux Preparations.*

The home preparation of Bordeaux mixture has a number of disadvantages: —

1. It involves a number of distinct operations which require considerable time.
2. The grower must keep in mind the proportions and various directions for preparation, or always have available the printed directions for the same (considered a nuisance by the average grower).
3. A number of suitable containers are required and are frequently not at hand when needed.
4. Few growers keep on hand a supply of quicklime, and even at the store it cannot always be obtained when wanted and of the quality wanted, especially in small quantities. When a barrel of lime is opened, it quickly carbonates, and the merchant in the small place is reluctant to break a barrel for a few pounds; while for the same reason the small grower does not wish to try to keep it at home.
5. The addition of a suitable insecticide in proper proportions increases the above objections.

The grower who uses large quantities of material may not hesitate to go to all this trouble, but the grower who operates on a small scale demands a fungicide which can be purchased ready-mixed, insecticide included, and which needs only to be diluted with water according to the directions on a convenient-sized package to be ready to apply. As early as 1893 — possibly earlier — Leggett & Brother of New York were putting on the market a dry Bordeaux. The Bowker Insecticide Company of Boston sold the concentrated paste "Bodo" at least as early as 1895. Since that time a great number of ready-mixed copper fungicides, usually with the insecticide included, have come into the market: *e.g.*, Pyrox, Caaseu, Kiltone, Adheso, Bordo-Lead, Tuber Tonic, etc.

Guaranties. — In compliance with the insecticide act of 1910, and the various rules and regulations which have been promulgated in interpretation of it, every package of commercial copper fungicide (not materials such as copper sulfate (bluestone), etc.) has on the label a statement of (1) the percentage of metallic copper, and (2) the percentage of inert ingredients which it contains. Thus one well-known commercial brand of dry Bordeaux mixture, typical of most of them, is guaranteed as follows: —

Active ingredient, metallic copper, not less than 11 per cent.
Inert ingredients, not more than 89 per cent.

The percentage of copper varies in different brands from 1.5 per cent to as much as 25 per cent, being, of course, higher in the powdered copper fungicides than in those which contain various percentages of water.

In case an insecticide which contains copper, *e.g.*, Paris green, is included, the guaranty states the amount of copper present as copper of Bordeaux, and in addition may also state the total amount of metallic copper in both the fungicide and the insecticide. In this case the copper of Bordeaux should be used as the basis for calculating the value of the substance as a fungicide. To the purchaser who has been accustomed to thinking in terms of 4–4–50 Bordeaux mixture, this statement of ingredients may mean but little. For this reason, Table II on page 33 is presented, interpreting the guaranties in terms of the standard 4–4–50 Bordeaux.

Now, while copper is the only active fungicidal principle in many of these materials, the value of a fungicide does not vary directly as the percentage of metallic copper. The physical character after it is diluted determines its power to cover and adhere to the foliage of the plant to be protected. A fungicide which is washed from the foliage with the first rain is worthless. It is just as important that the commercial substitute shall on dilution produce a voluminous gelatinous precipitate which "stands up" well as it is for the home-made Bordeaux. Commercial fungicides which lack this physical character are deficient in adhesive quality, and are therefore inferior to home-made Bordeaux, although they may contain as much copper.

The final test of the efficiency of a fungicide, however, is its proved ability in the field or experimental plot to check the disease for which it is used. It has been demonstrated in the field that many of these commercial copper preparations have value, but we know of no case in which carefully confirmed and repeated experiments by unbiased experimenters have shown them to be equal in efficiency to freshly prepared Bordeaux mixture. They are being rapidly improved, however, and we do not despair of seeing on the market within a few years an entirely satisfactory commercial Bordeaux preparation.

(3) *Pickering Sprays.*

These fungicides, variously called Woburn Bordeaux, lime-water Bordeaux, or Pickering sprays, were devised and investigated by Bedford and Pickering (34) of the Woburn Experimental Fruit Farm in England. They are made by mixing clear saturated limewater with dilute solutions of copper sulfate. It is claimed that they are more economical than Bordeaux, in that they contain no excess lime, and the copper is more efficient. They are said to deteriorate less rapidly than Bordeaux and are more easily applied. They have been but little investigated or used in America. Cook (35), however, after three years' tests, finds them just as effective as Bordeaux 4–4–50 for control of diseases of potatoes and cranberries in Maine and New Jersey. They did not injure the foliage, possessed good covering and adhesive properties, and apparently possessed the same stimulative properties. These sprays have not been used in Massachusetts.

2. Sulfur Fungicides.

The use of sulfur for disinfection of diseased plants was a common horticultural practice many years before the discovery of Bordeaux mixture. The date of its origin has not been recorded. It was sometimes used alone as a dust, and sometimes mixed with other substances such as lime. Thus in 1833 William Kenrick (36) recommended a mixture of 1½ pints of sulfur, a piece of quicklime as large as the fist, and 2 gallons of boiling water as a remedy for mildew of grapes. "Grison liquid," first prepared by a Frenchman, Grison, in 1851, was considered at that time very effective, and is of historical interest as being a prototype of our modern lime-sulfur solution. A mixture of flowers of sulfur, freshly slaked lime, and water was boiled for ten minutes, and the supernatant liquid diluted and applied with a sponge, especially for control of mildews (37). In these early years, it should be noted, sulfur fungicides were never applied for protection, but as cures. The idea of protective spraying seems never to have been considered previous to the discovery of Bordeaux mixture.

(1) *Lime-sulfur Solutions.*

The introduction of lime-sulfur into California from Australia for the control of San José scale has been described elsewhere in this bulletin (page 13). Shortly after the peach growers of that State began using it for the scale (about 1880), they noted that peach leaf curl, a fungous disease, was also controlled by the dormant spray. It immediately began to come into general use as a fungicide, first in the West, then in the East. Its use as a protective spray for other plant diseases began about 1907, with the observation by Cordley of Oregon (38) that when the dormant spray for scale was applied so late that the apple leaves had already unfolded, the scab disease was also checked. Experiment stations in all parts of the country began to investigate it, and within a few years it had almost supplanted Bordeaux as a spray for the apple orchard and for many other crops.

Formulas for Application. — Most of the commercial brands of lime-sulfur test about 33° by the Baumé hydrometer. As a summer spray for the orchard, this should be diluted at the rate of 1¼ gallons to the barrel. If the home-made solution is used it should be tested with the hydrometer, and the rate of dilution ascertained by consulting the dilution table on page 15 of this bulletin. The dilution for dormant spray (*e.g.*, for peach-leaf curl) is the same as recommended for San José scale under insecticides on page 15.

Effect on the Fungus. — When lime-sulfur is exposed to the air on the foliage, a process of oxidation begins (see page 14 for the equations representing this process), which results in the liberation of sulfur in a very fine state of division. It is the opinion of most investigators that it is this nascent sulfur — not the sulfite, sulfate or thiosulfate of calcium — which is of fungicidal value. The free sulfur is probably gradually oxidized

further to sulfur dioxide, which in water forms sulfurous, and on further oxidation, sulfuric acid. Both sulfurous and sulfuric acid are toxic to fungi. There is probably some chemical reaction between the acid and the protoplast of the fungus which results in the death of the latter.

Lime-sulfur Injury. — Lime-sulfur solutions are superior to Bordeaux mixture in that they cause less injury to foliage and rarely any fruit injury. Under certain conditions, however, which have not been very well defined, injury has resulted. Wallace (39) finds that this injury differs from that produced by Bordeaux in that it appears within a very short time after the spray is applied, and infers from this fact that it is due to the burning effect of the soluble polysulfides before the solution has dried on the leaves. It most often appears as irregular dead areas on the margins and tips of leaves where the liquid collects in larger drops and becomes more concentrated as it dries. Hence he warns against drenching the leaves. Addition of lime seems to have no effect on this injury. Injury is worse where the leaves have been previously wounded by insects, scab or other agencies, and the solution has direct access to the interior tissues. Different crops show different degrees of susceptibility to injury. Peach trees are often entirely defoliated by lime-sulfur of a strength that is entirely safe on apples. Pears show varietal differences in this respect, the Duchess being very easily injured. The orchardists of Nova Scotia have within the last few years almost abandoned the use of lime-sulfur spray because it causes a serious dropping of the fruit. Such damage has not been noted in this State.

(2) *Self-boiled Lime-sulfur.*

The use of mechanical mixtures of sulfur and lime dates far back into the history of plant-disease control. Freshly slaked lime provided a cheap base for a paste suitable for applying and distributing the flowers of sulfur. The only sources of heat in these early mixtures were the hot water sometimes recommended for mixing, and the reaction of the lime in slaking. But sulfur fungicides were almost forgotten during the quarter century which followed the introduction of Bordeaux. The use of the self-boiled mixture in its present form was revived by Scott (40) of the United States Department of Agriculture in 1907 for the control of brown rot and scab of peaches. Bordeaux mixture and sulfur fungicides which contain sulfur in solution were found to be highly injurious to peach foliage when applied at a concentration sufficient to control these diseases. Scott found that this mixture, which contains but a very small percentage of soluble sulfur at most, gave good control of the diseases and caused no burning of the foliage. Within a few years it became the most extensively used and successful fungicide for peaches and plums throughout the country. Objections to the use of self-boiled lime-sulfur are: —

1. The poor suspension of ingredients necessitates constant strong agitation and frequent cleaning of nozzles.

2. Especially in dry seasons, it leaves deposits on the fruit if applied within a few weeks of ripening.

3. The labor costs of preparation are exceedingly heavy.

Formula. — The 8–8–50 formula is now used almost exclusively (8 pounds of quicklime, 8 pounds of sulfur, 50 gallons of water).

Physical and Chemical Properties. — This is a mechanical mixture, or, at most, there is only a minimum amount of chemical union between the lime and sulfur. In explanation of the part played by the lime, Scott (41) says: "The intense heat seems to break up the particles of sulphur into about the physical condition of precipitated sulphur, and the violent boiling makes a good mechanical mixture of the lime and sulphur. The finely divided sulphur is depended upon for the fungicidal action rather than the sulphids in solution." The lime also gives adhesive qualities.

The result, then, is the same in the end, whether the commercial lime-sulfur or the self-boiled is used, — sulfur in a finely divided form is deposited on the leaves, and the fungus is killed or checked in its development as described above (page 26).

(3) *Sulfur Dust.*

The use of sulfur dust as a protective application was first begun in New York State and most energetically pushed by Whetzel, Reddick, Blodgett *et al.* of the Cornell Experiment Station. Since its beginning in New York State in 1912, experiment station workers in Michigan, Georgia, Illinois, Virginia, West Virginia, Maryland, Nova Scotia, and Ontario have conducted orchard tests with the dust as a possible substitute for the lime-sulfur and lead arsenate spray. The published results from New York, Michigan, Illinois, Nova Scotia, and Ontario indicate an efficiency equal to that of lime-sulfur and lead arsenate for the control of apple scab and codling moth. Virginia and West Virginia workers report satisfactory control of codling moth, but find it unsatisfactory for black rot, bitter rot, rust and scab of apples, and (in Virginia) for brown rot of peaches. Peach dusting experiments in Georgia and West Virginia indicate an efficiency against scab and curculio equal to that of the sulfur spray, and slightly less control for brown rot. Results in Maryland are less favorable to control of orchard fungi by dusting than by spraying. Whether it is better to dust than to spray and just what diseases can be better controlled by dusting are questions that have by no means been fully answered. Dusting has many opponents as well as advocates among both scientists and practical growers. No great body of experience has yet been developed in Massachusetts, and lacking this, the question cannot be satisfactorily answered.

Formulas. — The sulfur dust is still in the experimental stage, and the proportion of sulfur to lead arsenate or to inert "fillers" has not become standardized. The most used formula calls for 90 parts of very finely ground sulfur to 10 parts of the fluffy type powdered lead arsenate. "Fillers," such as hydrated lime, "terra alba," etc., have been used in some places. The material may be bought ready-mixed or mixed with machine at home. Various types of dusting machines for application are now on the market.

II. DISINFECTANTS.

1. Corrosive Sublimate.

This fungicide (known also as mercuric chloride or mercury bichloride) is used only as a disinfectant. Its toxicity to foliage and its solubility prevent its use as a spray. Its only use in Massachusetts on the farm or in the orchard is for disinfection of seed potatoes and of wounds on trees produced by pruning, canker removal, etc. Corrosive sublimate is a white, dry crystalline salt which may be secured in the market in the powdered form or as tablets. The tablets, which are commonly purchased at drug stores, are of such a size that one tablet produces a 1–1,000 solution when dissolved in a pint of water.

Formula. — Corrosive sublimate for all purposes is used at a dilution of 1–1,000. This dilution may be secured by dissolving 2 ounces of the salt in 15 gallons of water.

2. Formaldehyde.

Formaldehyde is a toxic gas extensively used as a disinfectant since 1888. Its ability to kill fungi and bacteria is dependent on its reducing power, that is, on its power to remove oxygen from matter with which it comes in contact. The formaldehyde (formalin) which is sold on the market is a solution of the gas in water. According to the United States standard of purity for interstate commerce, 37 per cent of the weight must be formaldehyde gas. Although commonly spoken of as a 40 per cent solution, analyses of samples in recent years have shown it to be frequently much lower, even down to 32 per cent. Also, a white sediment (paraformaldehyde) is frequently deposited in the bottom of containers. Since the formation of paraformaldehyde lowers the percentage of formaldehyde, the solution should be warmed until the white sediment has disappeared before it is used. Commercial formaldehyde also contains 5–10 per cent or more of wood alcohol, but this does not impair its fungicidal value. The fumes are very irritating to the nose and eyes, but it is a safer disinfectant than corrosive sublimate.

Uses and Formulas. — The use of formaldehyde (formalin), at a dilution of 1 part in 240 (1 pint to 30 gallons), for disinfection of seed potatoes against scab has now been almost discontinued in favor of corrosive sublimate because the latter is also effective against black scurf.

For disinfection of grain seed against smut, a dilution of 1–240 is recommended except where the spray method is used. In the latter case equal parts of commercial formaldehyde and water are used.

For onion smut the 1–128 formula has been recommended most extensively.

C. COMBINED INSECTICIDES AND FUNGICIDES.

Most farm and orchard crops suffer from both insect pests and fungous diseases. This necessitates the use of both an insecticide and a fungicide on the same plant. Frequently, also, the presence at the same time of more than one species of insect requires the application of both a stomach poison and a contact insecticide. If the crucial time for application of more than one should be approximately the same, it is usually possible and profitable to combine them in a single application. Such a combination results in the saving of one-half to two-thirds of the time required for separate applications, and since labor is usually the big item of expense in spraying, the cost is materially diminished. Unfortunately, however, it is not possible to combine indiscriminately the various substances which are used as fungicides and insecticides. Frequently, in combining two or more of them a reaction takes place which results in —

1. Complete or partial neutralization of the beneficial qualities of one or more.
2. Formation of a new compound which will injure the plant.
3. Liberation of some harmful element.

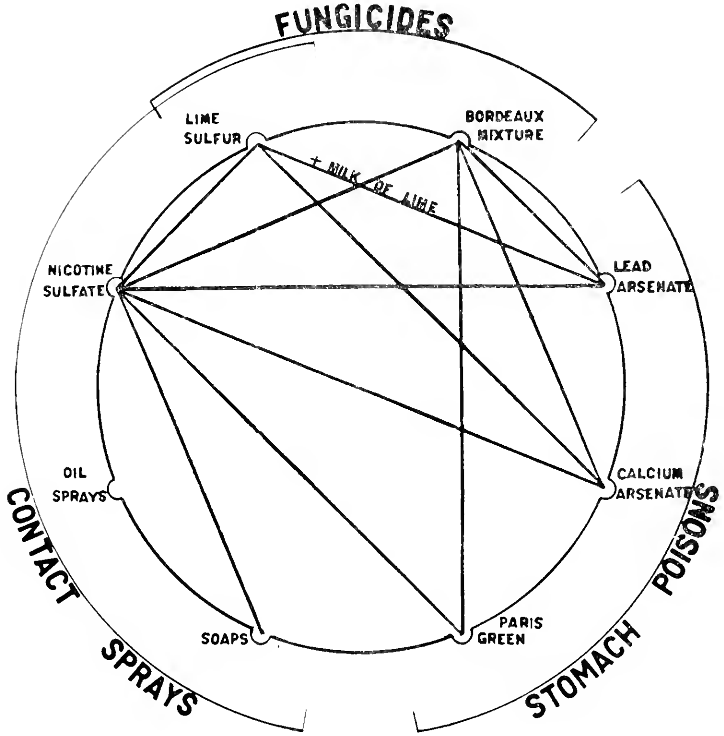
Such substances are said to be incompatible. It should not be understood, however, that chemical combinations between fungicides and insecticides are always harmful or undesirable. Sometimes the reaction is known to increase rather than decrease the fungicidal value; in other combinations the substances have no effect on each other. The possible combinations are discussed below, and the compatibilities graphically represented in the diagram opposite this page.

In making combinations, the formulas and methods of preparation should be the same as have been previously described for each material.

1. Bordeaux Mixture with Lead Arsenate or Calcium Arsenate.

Bordeaux mixture can be combined safely with lead arsenate or calcium arsenate. There is, however, some experimental evidence to show that, in such a combination, the fungicide inhibits the action of the arsenical to a considerable extent (42). On the other hand, the excess lime of the Bordeaux combines with any arsenic rendered soluble by atmospheric conditions, thus diminishing the danger of foliage injury. Owing to its superior adhesive qualities, lead arsenate is better than calcium arsenate for combination with Bordeaux. On the other hand, calcium arsenate is much cheaper. The choice between these, therefore, seems to be a matter of personal preference.

MIXING SPRAY MATERIALS.



DESIRABLE COMBINATIONS
UNDESIRABLE COMBINATIONS

ADAPTED FROM CIR. 195 CAL. EXP. STA.

2. Bordeaux Mixture with Paris Green.

These two can be combined safely. The excess lime in the Bordeaux unites with any free arsenic which may be present in the insecticide, and thus protects the leaves from arsenical injury. Paris green also has fungicidal value (43); the combination, therefore, is slightly more beneficial than the fungicide alone. No injurious or neutralizing reaction occurs between the two materials.

3. Proprietary Copper Preparations.

Most of these preparations have the constituents of Bordeaux mixture with the addition of a stomach poison, usually lead arsenate but occasionally Paris green. Both are compatible with the fungicide, and the effect should be the same as previously described for combinations of these arsenicals with Bordeaux.

The tendency of manufacturers of commercial copper mixtures has been to recommend the dilution of their product to a copper content lower than that of 4–4–50 Bordeaux. Within recent years, however, they have been increasing the amount of copper and recommending a more concentrated application. The percentage of arsenic has been more nearly that recommended by entomologists for control of insects. Thus when the purchaser has mixed in his spray tank enough of a low-copper preparation to conform to the standard given in Table II, he will have the arsenical in great excess of the amount needed, and therefore is paying a very high price for his arsenic.

The manufacturer is required to state on the label the amount of arsenic which is present, either as metallic arsenic or as arsenic or arsenous oxide. As an aid to the purchaser in making dilutions and in estimating the value of the preparation, Table II shows the guaranteed arsenic content and the amount of material required to furnish arsenic equivalent to the standard formula (0.293 pound of metallic arsenic to 50 gallons of water).

4. Bordeaux Mixture with Lead Arsenate or Calcium Arsenate and Nicotine Sulfate.

These materials are compatible and make an efficient combination. Some hesitancy was felt at first in regard to the safety of such a combination, owing to the supposed reaction between copper and tobacco compounds, and the possibility of serious burning of foliage by the resulting products (44). It has been demonstrated, however, by chemical analyses and extensive field tests, that there is no objectionable reaction when nicotine in the form of sulfate is combined with Bordeaux mixture; hence this combination may be used (45).

In preparing this spray the nicotine sulfate should be added just before application, and thorough agitation should be given to insure an even

distribution of the highly concentrated nicotine product throughout the mixture.

Soap should *never* be added when nicotine sulfate is used in this combination.

5. Lime-sulfur with Lead Arsenate or Calcium Arsenate.

The great extent to which sulfur compounds have supplanted copper sprays as fungicides has made this combination probably the most widely used and most important in practice to-day.

When lead arsenate is added to lime-sulfur, a chemical reaction takes place causing more or less decomposition of both materials. This reaction does not decrease the fungicidal value of the mixture. In fact, Wallace (46), in his investigation of apple scab control, found that the addition of lead arsenate increased the fungicidal action of the lime-sulfur by about 50 per cent. The fact has long been recognized that arsenate of lead alone has some value as a fungicide.

The effect of this reaction upon the value of the combination as an insecticide, however, is unfavorable. In the case of the *acid* lead arsenate (90 per cent of that on the market to-day is of this type), the reaction with lime-sulfur results in the formation of a considerable percentage of soluble arsenic, with the consequent danger of severe foliage injury. The addition of milk of lime, 5 pounds to 50 gallons of the mixture, checks this reaction and so reduces the tendency to burn foliage (47). The arsenate of lead should be added to the milk of lime, and the two thoroughly mixed together and then poured into the lime-sulfur solution so that the protective agent may be present when the two active ingredients are brought together.

When calcium arsenate is used with lime-sulfur, so far as known no chemical change takes place which decreases the value of the combination either as an insecticide or as a fungicide. The addition of milk of lime, however, as a precautionary measure seems advisable.

6. Lime-sulfur with Lead Arsenate or Calcium Arsenate and Nicotine Sulfate.

These materials can be combined successfully and effectively. The presence of nicotine sulfate is not known to modify any of the reactions mentioned under 5, and the recommendations there made apply to this combination also.

The suggestions relative to the addition of nicotine sulfate to the spray, and caution regarding the use of soap, apply here as in 4 above.

TABLE II. — *Combined and Uncombined Insecticides and Fungicides.*

Amounts required to furnish metallic copper and arsenic in quantities equivalent to those in a standard 4-4-50 Bordeaux with arsenical.

Commercial Bordeaux.			Commercial Arsenates.		
Guaranty of Metallic Copper (Per Cent).	For 50 Gallons of Spray (Pounds).	For 1 Gallon of Spray (Ounces).	Guaranty of Metallic Arsenic (Per Cent).	For 50 Gallons of Spray (Pounds).	For 1 Gallon of Spray (Ounces).
25.0	4 00	1 25	30 0	1 00	.25
20 0	5 00	1 50	25 0	1 25	.25
15 0	6 75	2 25	20 0	1 50	.50
12 5	8 25	2 50	17 5	1 75	.50
10 0	10 25	3 25	15 0	2 00	.75
9 0	11 25	3 75	10 0	3 00	1 00
8 0	12 75	4 00	9 0	3 25	1 00
7.5	13 50	4 25	8 0	3 75	1.00
7.0	14 50	5.00	7 0	4 25	1 25
6.5	16 00	5 00	6.0	5.00	1 50
6 0	17.00	5 50	5 0	5 75	2.00
5.5	18 50	6 00	4.5	6 50	2 00
5 0	20 00	6 50	4 0	7 00	2 50
4 5	22 50	7.00	3 5	8 00	2 75
4 0	25 50	8 00	3 0	10 00	3 25
3.5	29.00	9 00	2 5	12 00	3 75
3 0	34 00	12 00	2 0	15 00	4 75
2.5	41 00	13 00	1 5	19 50	6.25
2.0	51 00	16.00	1.0	29 00	9 50
1 5	68 00	22 00	.5	58 00	19 00

APPENDIX.

Commercial Bordeaux Mixtures.

Brands and Guaranteed Composition.

Manufacturer and Brand.	Metallic Copper (Cu) (Per Cent).
J. A. Blanchard Company, New York City: —	
Lion Brand,	4.00
Lion Brand (dry),	11.00
Corona Chemical Company, Milwaukee, Wis.: —	
Corona Dry Bordeaux Mixture,	11.00
Dow Chemical Company, Midland, Mich.: —	
No brand name given,	25.00
Grasseli Chemical Company, Cleveland, Ohio: —	
Bordeaux mixture (dry),	13.00
Sherwin-Williams Company, Cleveland, Ohio: —	
Fungi-Bordo,	11.00
Sterling Chemical Company, Cambridge, Mass.: —	
Sterlingworth (liquid),	3.00
Sterlingworth (dry),	10.00

Commercial Bordeaux with Insecticides.

Brands and Guaranteed Composition.

Manufacturer and Brand.	Metallic Copper (Cu) (Per Cent).	Metallic Arsenic (As) (Per Cent).
Bowker Insecticide Company, Boston, Mass.: —		
Pyrox,	2.30	3.42
Detroit White Lead Works, Detroit, Mich.: —		
Rogers Leaded Bordo,	10.50	2.75
Frost Insecticide Company, Arlington, Mass.: —		
Bordo Lead,	5.00	2.90
Interstate Chemical Company, Jersey City, N. J.: —		
Bordo Lead,	2.00	5.00
Sherwin-Williams Co., Cleveland, Ohio: —		
Pestroy,	10.50	2.75
Tuber Tonic,	6.00	24.00
Sterling Chemical Company, Cambridge, Mass.: —		
Sterlingworth Ar-Bo,	4.00	1.65
Thomsen Chemical Company, Baltimore, Md.: —		
Bordo Lead, Orchard Brand,	5.40	3.90
Toledo Rex Spray Company, Toledo, Ohio: —		
NuRexo,	12.70	3.60
Leggett & Brother, New York City: —		
Dry Bordeaux and Paris Green Compound,	7.00	12.50
Sterling Chemical Company, Cambridge, Mass.: —		
Sterlingworth Dry Bordeaux and Paris Green Compound,	9.00	2.00

LITERATURE CITED.

(1) Liddle, Geo., Sr.
1869. To destroy Colorado Potato Bugs. In Amer. Ent., Vol. 1, No. 11, p. 219.

(2) Holland, E. B., and Reed, J. C.
1912. The Chemistry of Arsenical Insecticides. In Mass. Agr. Expt. Sta. Ann. Rpt. 24, Pt. 1, p. 178.

(3) Riley, C. V.
1876. Potato Pests. P. 67.

(4) Lodeman, E. G.
1896. The Spraying of Plants. P. 65.

(5) Kilgore, B. W.
1891. On the Cause and Prevention of the Injury to Foliage by Arsenites together with a New and Cheap Arsenite, and Experiments on combining Arsenites with Some Fungicides. N. C. Agr. Expt. Sta. Bul. 77*b*, p. 7, 8.

(6) Forbush, E. H.
1894. Report of the State Board of Agriculture on the Work of Extermination of the Gypsy Moth — Field Director's Report. In Mass. State Bd. Agr. Ann. Rpt. 41, 1893, p. 282.

(7) Fernald, C. H.
1898. Arsenate of Lead as an Insecticide. In Mass. State Bd. Agr. Ann. Rpt. 45, 1897, p. 353.

(8) Smith, Frederic J.
1898. Arsenate of Lead: Its Manufacture and Chemical Composition. In Mass. State Bd. Agr. Ann. Rpt. 45, 1897, p. 357–369.

(9) Smith, G. Ennis.
1916. Lead Arsenates. In Jour. Amer. Chem. Soc., Vol. 38, p. 2016–2018.

(10) McDonnell, C. C., and Smith, C. M.
1916. The Arsenates of Lead. In Jour. Amer. Chem. Soc., Vol. 38, p. 2033 and 2035.

(11) Robinson, R. H., and Tartar, H. V.
1915. The Arsenates of Lead. Ore. Agr. Expt. Sta. Bul. 128, p. 13.

(12) Headden, Wm. P.
1908. Arsenical Poisoning of Fruit Trees. Colo. Agr. Expt. Sta. Bul. 131, p. 21, 22.
1910. Arsenical Poisoning of Fruit Trees. Colo. Agr. Expt. Sta. Bul. 157, p. 28–31.

(13) Haywood, J. K., and McDonnell, C. C.
1910. Lead Arsenate. U. S. Dept. Agr. Bur. Chem. Bul. 131, p. 45–49.

(14) United States Congress.
1910. An Act for preventing the Manufacture, Sale or Transportation of Adulterated or Misbranded Paris Greens, Lead Arsenates, and Other Insecticides, and also Fungicides, and for regulating Traffic therein, and for Other Purposes. Statutes at Large, chapter 191, section 7.

(15) Robinson, R. H.
1918. The Calcium Arsenates. Ore. Agr. Expt. Sta. Bul. 131, p. 7.

(16) Woodworth, C. W., and Colby, G. E.
1899. Paris Green for the Codling Moth. Cal. Agr. Expt. Sta. Bul. 126.

(17) Mitchell, A.
1842. Hellebore Powder and Gooseberries. In Gard. Chron., No. 25, p. 397.

(18) Fruit Growers' Society of Western New York.
1865. The Currant Worm. Report of Meeting of June 21. In Country Gentleman, Vol. 25, No. 26, p. 413.

(19) Lodeman, E. G.
1896. The Spraying of Plants. P. 14.
(20) Gray, George P.
1914. The Compatibility of Insecticides and Fungicides. In Mo. Bul. State Com. Hort. Cal., Vol. 3, No. 7, p. 271.
(21) Quayle, H. J.
1905. Spraying for Scale Insects. Cal. Agr. Expt. Sta. Bul. 166, p. 6.
(22) Stewart, John P.
1909. Concentrated Lime-sulphur. Its Properties, Preparation and Use. In Penn. State Col. Rpt. for 1908-09, p. 262.
(23) Salmon, D. E., and Stiles, C. W.
1898. Sheep Scab: Its Nature and Treatment. U. S. Dept. Agr. Bur. Anim. Indus. Bul. 21, p. 24, 25.
(24) VanSlyke, L. L., Bosworth, A. W., and Hedges, C. C.
1910. Chemical Investigation of Best Conditions for making the Lime-sulphur Wash. N. Y. (Geneva) Agr. Expt. Sta. Bul. 329, p. 438.
(25) Scott, W. M.
1915. A New Contact Insecticide. In Jour. Econ. Ent., Vol. 8, No. 2, p. 206-210.
(26) Cruickshanks, Geo.
1875. The Currant. In Gardeners' Monthly, p. 45.
(27) Cook, A. J.
1890. Insecticides. Mich. Agr. Expt. Sta. Bul. 58.
(28) Riley, C. V.
1884. Kerosene Emulsions. In Ann. Rpt. Com. Agr. United States, p. 330.
(29) Felt, E. P.
1909. 25th Rpt. State Entomologist, New York.
(30) McIndoo, N. E.
1916. Effects of Nicotine as an Insecticide. In Jour. Agr. Research, Vol. 7, No. 3, p. 89.
(31) Moore, William, and Graham, Samuel A.
1917. A Neglected Factor in the Use of Nicotine Sulphate as a Spray. In Jour. Agr. Research, Vol. 10, No. 1, p. 47.
(32) Butler, O.
1914. Bordeaux Mixture: I. Physicochemical Studies. In Phytopathology, Vol. 4, p. 125-180.
(33) Hedrick, U. P.
1907. Bordeaux Injury. N. Y. (Geneva) Agr. Expt. Sta. Bul. 287.
(34) Bedford, Duke of, and Pickering, S. N.
1908. Bordeaux Mixture. Woburn Expt. Fruit Farm Rpt. 8, p. 1-127.
1910. Copper Fungicides. Woburn Expt. Fruit Farm Rpt. 11, p. 1-191.
(35) Cook, F. C.
1920. Pickering Sprays. U. S. Dept. Agr. Bul. 866.
(36) Kenrick, William.
1833. The New American Orchardist. P. 328.
(37) Lodeman, E. G.
1896. The Spraying of Plants. P. 16.
(38) Cordley, A. B.
1908. Lime-sulphur Spray to prevent Apple Scab. In Better Fruit, Vol. 3, No. 3, p. 26.
(39) Wallace, Errett.
1910. Spray Injury induced by Lime-sulfur Preparations. N. Y. (Cornell) Agr. Expt. Sta. Bul. 288.
(40) Scott, W. M.
1908. Self-boiled Lime-sulphur Mixture as a Promising Fungicide. U. S. Dept. Agr. Bur. Plant Indus. Circ. 1, p. 1-18.

(41) Scott, W. M.
1909. Lime-sulphur Mixtures for the Summer Spraying of Orchards. U. S. Dept. Agr. Bur. Plant Indus. Circ. 27.

(42) Sanders, G. E., and Brittain, W. H.
1916. The Toxic Value of Some Common Poisons Alone and in Combination with Fungicides, on a Few Species of Biting Insects. In Proc. Ent. Soc. Nova Scotia, No. 2, p. 55.

(43) Jordan, W. H., Stewart, F. C., and Eustace, H. J.
1905. Effect of Certain Arsenites on Potato Foliage. N. Y. (Geneva) Agr. Expt. Sta. Bul. 267.

(44) Gray, George P.
1914. The Compatibility of Insecticides and Fungicides. In Mo. Bul. State Com. Hort. Cal., Vol. 3, No. 7, p. 265 273.

(45) Safro, V. I.
1915. The Nicotine Sulphate-Bordeaux Combination. In Jour. Econ. Ent., Vol. 8, No. 2, p. 199.

(46) Wallace, Errett.
1911. Lime-sulfur as a Summer Spray. N. Y. (Cornell) Agr. Expt. Sta. Bul. 289.

(47) Robinson, R. H.
1919. The Beneficial Action of Lime in Lime-sulfur and Lead Arsenate Combination Spray. In Jour. Econ. Ent., Vol. 12, No. 6, p. 429.

BULLETIN No. 202.

DEPARTMENT OF BOTANY.

RUST OF ANTIRRHINUM.[1]

BY WILLIAM L. DORAN.

Introduction.

The cultivated snapdragon (*Antirrhinum majus* L.) is a biennial or perennial under culture. It is a member of the family Scrophulariaceæ. The plant was introduced here from Europe. As an escape from gardens it is rare in New England. The snapdragon has been a popular garden flower for two hundred years, but only within the last ten years has it been grown to any extent as a greenhouse crop. There has been an increasing demand for it as a cut flower, and consequently an increasing amount of glass has been devoted to its culture. As a florist's crop, the snapdragon may be classed as about equal in importance to mignonette, schizanthus, stocks, pansies and primulas (Nehrling, 1914), varying, of course, in different localities.

Growers have propagated principally for the best colored blossoms and the best formed spikes, and relatively slight attention has been paid to the susceptibility of the plants to disease. Increased and intensive cultivation seem to have weakened this once hardy plant, for it is now affected severely by at least four fungous diseases. The diseases of snapdragon, other than rust, are: anthracnose or leaf-spot, caused by *Colletotrichum Antirrhini*, Stew. (Stewart, 1900), and stem-rot and leaf-spot, caused by *Phyllosticta Antirrhini*, Syd. (Guba and Anderson, 1919).

Rust is the most serious of the diseases of snapdragon under glass; but according to the observation of the writer, anthracnose is in most years a more serious disease than rust on plants grown outdoors. The investigation of snapdragon rust was undertaken by the writer because of the economic importance of the disease, and because so little information

[1] Presented to the faculty of the Graduate School of the Massachusetts Agricultural College (May, 1917) in partial fulfillment of the requirements for the degree of master of science. Literature citations are brought up to the date of presentation for publication (January, 1921). The writer wishes to express his indebtedness to Prof. A. V. Osmun of the Massachusetts Agricultural College and to Dr. O. R. Butler of the New Hampshire Agricultural Experiment Station, under whose direction the work here described was carried on.

concerning the disease was available to the growers. Rust causes loss in at least three ways. A spike of snapdragon blossoms is useful only when it is beautiful, and the rust pustules on leaves and stem considerably mar the appearance and hence lessen the value of otherwise salable spikes. An attack of rust impairs the vitality of the host plant, and results in smaller flowers and shorter spikes than the normal. In severe cases the stems and branches are girdled, causing the death of the plant.

History and Distribution.

Snapdragon rust was found in California in 1895 (Blasdale, 1903). The causal organism was described in 1899 under the name of *Puccinia Antirrhini* Diet. and Holw. (Dietel, 1899). In 1913 the disease was found in Illinois, and in 1914 it was found in Ohio and Indiana (Rees, 1914). By 1915 the rust had appeared in Wisconsin and Iowa (Peltier, 1919). In 1915 the writer observed the disease in Maine, New Hampshire, Massachusetts, Rhode Island and Connecticut, and it was well established in New England, both out of doors and under glass. In this year, also, it was reported from Oregon (Bailey, 1915). In 1916 it was reported from Guelph and Montreal, Can., and also from Alabama (Peltier, 1919). It was found in Nebraska in 1916–17, and is now known to occur in Missouri (Thurston, 1919). Snapdragon rust is evidently generally distributed over the United States, more especially in the northern part.

Symptoms.

Snapdragon rust may occur on plants of all ages from cuttings and seedlings just beginning to show foliage leaves up to mature blossoming plants. A severely attacked snapdragon has a most dejected appearance. The leaves hang limp and wilted as if the plant had been deprived of water, the flowers open small and prematurely, and leaves and stems bear chocolate-brown powdery pustules each edged by a yellowish ring. Leaf blades, petioles, stems and calyces are attacked. Usually the lower leaves of the plant are most affected.

In the early stages there appear on the under side of the leaves swollen yellow patches just inside the epidermis. These yellow patches are 1 to 7 mm. in diameter. At this time the leaf may curl slightly. About forty-eight hours after these yellow patches first appear the epidermis is ruptured, exposing brown powdery masses beneath. These brown spore masses, the uredinia, have been described as being usually circularly grouped (Clinton, 1915), but according to the writer's observation this circular grouping is not an especially dependable characteristic. On the upper surface of the affected leaves are yellow blotches, corresponding in position to the uredinia beneath. The spore powder in the uredinia is in an agglutinate condition at first, but after a few days it becomes dry and dusty and is easily blown about. The uredinia are not sunken. They are confluent with age. The ring of ruptured epidermis surrounding a uredinium is soon concealed by this brown spore powder.

PLATE I.

Snapdragon plant attacked by *Puccinia Antirrhini*.

The uredinia on the stem are much elongated. Here the ruptured epidermis is more noticeable than on the leaves. Uredinia on the stem usually occur at the base of a petiole, or at the crotch of two branches, or any place where water may stand. It is the girdling of the stem by uredinia which causes the branch or plant to wilt and die. It is not especially common, however, for snapdragon rust to cause the death of the host plant.

The telia are black, not brown. They are leathery, not powdery, and must be scraped off if they are to be removed. Telia are more common on stems than on leaves, but are not numerous anywhere. They are slightly smaller than the uredinia and are usually somewhat sunken, with the ruptured cuticle projecting above them. Teliospores are sometimes borne in the same sorus with the urediniospores, but the telia may be distinguished macroscopically by their blacker color and harder consistency.

In the greenhouse the disease occurs at all seasons of the year, but is more serious and conspicuous during April and May.

Causal Organism.

Morphology.

Snapdragon rust is caused by the fungus *Puccinia Antirrhini* Diet. and Holw. The mycelium of the fungus occurs chiefly between the spongy parenchyma cells of the leaf and between the cortex cells of the stem. It is more abundant in the leaf than in the stem. It is colorless, septate frequently, and branches profusely. It is intercellular and provided with haustoria (Fig. 4, Plate 2). The haustoria are constricted at the point of entrance to the cell. Within they become broader and vase-shaped, or bear short knoblike branches. A dilute solution of eosin makes the haustoria easily visible. A cross section through an infected leaf reveals beneath each uredinium a stroma of interwoven mycelium (Figs. 1 and 5, Plate 2). This stroma underlies the whole sorus, and extends in a ring around its edge. From this stroma the spore-bearing hyphæ arise.

Two types of spores are known in the life cycle of the fungus, viz., urediniospores and teliospores. The urediniospores are spherical to elliptical. They are 22 to 30 microns in length and 21 to 25 microns in diameter. They are borne on pedicels of varying length from which they become detached at maturity. The urediniospores are yellowish brown in color. Their walls are provided with short spines and have two or three germ pores. The teliospores are 36 to 50 microns in length and 17 to 26 microns in diameter. These spores vary greatly in shape (Fig. 2, Plate 2). The apex may be sharply pointed, rounded or truncate; the base is usually attenuated, but may be rounded off bluntly. There is a slight constriction at the septum. The epispores are dark brown to black, and the wall is smooth, possessing no such spines as occur on the urediniospores. Each of the two cells of the teliospore is provided with a germ tube which is apical in the terminal cell and occurs just below the septum of the basal cell.

PLATE II.

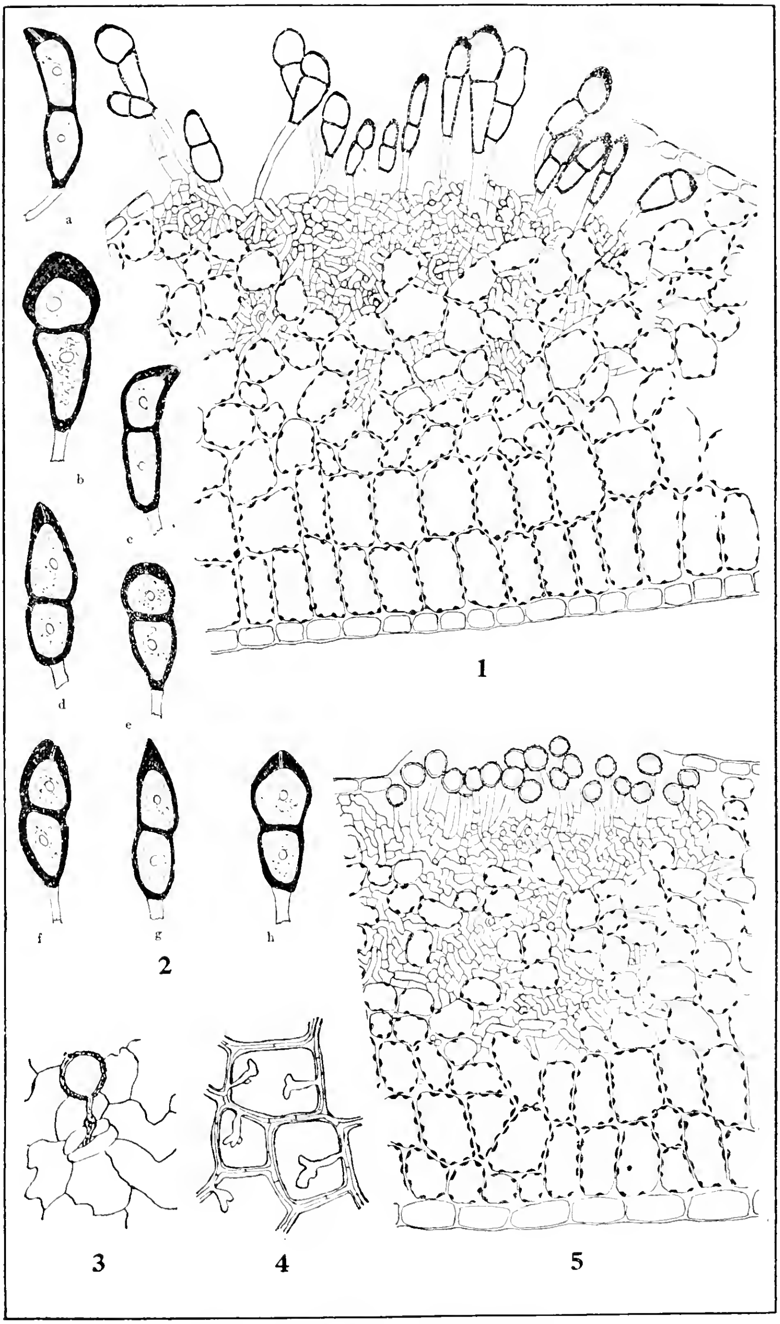


FIG. 1. — Cross section of telium and leaf.
FIG. 2. — Teliospores.
FIG. 3. — Germinating urediniospore on leaf.
FIG. 4. — Haustoria and intercellular mycelium.
FIG. 5. — Cross section of uredinium and leaf.

Occurrence of Spore Stages.

Urediniospores occur at all times on the diseased snapdragons. In the greenhouse these are normally the only type of spores produced. Teliospores occur only rarely in New England. Many infected plants bear only urediniospores, even on the advent of killing frosts. Occasionally teliospores may be found outdoors in November, occurring more often on the stems than on the leaves. In November the writer placed several snapdragons bearing uredinia in wire baskets and allowed them to winter over out of doors in this way. Examination the following March showed only one telium on all the material.

In the greenhouse there is no lowering of temperature to stimulate the formation of teliospores, but their formation is stimulated if the host plant dries out very slowly. When plants were suddenly dried out, no teliospores were formed; but when plants were gradually deprived of water, teliospores were formed in five weeks. Under normal conditions of culture the teliospore may be eliminated as a factor in the greenhouse. No greenhouse snapdragons seen by the writer showed teliospores except those plants gradually deprived of water, as above mentioned.

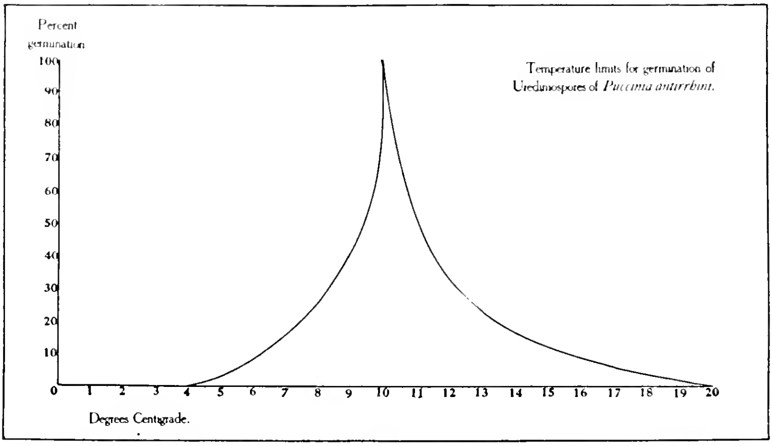
Spore Germination and Infection Experiments.

The first attempts made to germinate urediniospores were not uniformly successful. As it proved later, this was because the room temperature at which the tests were made was above the maximum temperature for spore germination. The method by which the minimum, optimum and maximum temperatures for the germination of these spores were determined is here described. This method has been previously described by the writer (Doran, 1919).

The spores to be used were removed from infected leaves by a stream of water from a pipette. In this way only mature spores were obtained, while scraping with a brush or wooden instrument would also detach young and immature spores. The spores were shaken in distilled water until they were uniformly distributed through it. Drops of this water containing the spores were then placed on clean slides, and the latter were placed on culture plate benches in moist chambers. These were placed in biological incubators at constant temperatures. About twelve hours later the germinated and ungerminated spores were counted. Most of the spores which germinated did so, however, in five to eight hours. Throughout these tests it was noticeable that no spores in the interior of the drop ever germinated. Only those spores in contact with the air as well as the water germinated, so spores in the interior of the drop were not counted as being present. The distilled water used was not aërated. This aërotropism was not further investigated. Throughout the tests one lot of spores was always run at 10° C. The percentage of germination at 10° C. was taken as a standard, raised to 100, and the other percentages at the different temperatures raised proportionately. This was done in

order to bring the data into shape for plotting a constant curve of temperature and germination.

PLATE III.



Curve showing temperature limits for germination of urediniospores of *Puccinia Antirrhini.*

The optimum temperature for the germination of the urediniospores of *P. Antirrhini* was found to be 10° C., the minimum, 5° C., and the maximum, 20° C. When the data are plotted, a curve is obtained that is nearly symmetrical. A most striking fact is that if the temperature is varied 2° C. above or below the optimum, the germination falls off 50 per cent. In the following table each relative germination is the mean of five experiments: —

TABLE 1. — *Relative Germination of Urediniospores of P. Antirrhini Diet. and Holw., compared to the Germination at 10° C. taken as 100.*

5° C.	6° C.	7° C.	8° C.	9° C.	10° C.	11° C.	12° C.	14° C.	15° C.	18° C.	20° C.	30° C.
0	0	27	13	50	100	–	21	0	17.5	2.5	0	0
0	0	0	35	30	100	42	15	12	13	0	1	0
1	4	7	37	50	100	9	32	0	0	0	1	0
0	0	–	4	12	100	14	16	42	6	1.5	0	0
1	4	–	21	30	100	72	–	2	1	1	0	0
0	3	–	–	–	100	–	–	22	–	0.5	0	0
0.3	1.8	11.3	22	34.4	100	34.2	21	13	7.5	.75	0.2	0

Conditions affecting Longevity of Urediniospores.

The spores used in the previously described germination tests were taken fresh from growing plants. It was noticeable that their viability gradually diminished if the leaves dried out long in the room. To determine

the longevity of urediniospores, rusted shoots were removed from the plants and placed at temperatures of 0° C., 10° C. and 22° C. Half of this material at each temperature was allowed to dry in open containers, and half of it was kept in closed chambers to prevent its drying out. Spores were removed every seven days and placed at their optimum temperature for germination, with the results shown in Table 2.

TABLE 2. — *Effect of Temperature and Drying on the Longevity of the Urediniospores of P. Antirrhini.*

Percentage of germination of urediniospores.

Storage Period (Days).	Storage Temperature.					
	Dry.			Moist.		
	0° C.	10° C.	22° C.	0° C.	10° C.	22° C.
7,	55	50	40	52	52	50
14,	35	25	28	35	20	25
21,	20	20	15	18	12	20
28,	12	15	12	18	15	15
35,	1	2	3	10	6	5
42,	0	0	0.5	3	2	2
49,	0	0	0	1	1	0
56,	0	0	0	0	0	0

When this experiment was begun, 60 per cent of the spores germinated. Some of the spores in moist air retained the power of germination forty-nine days, and in dry air, forty-two days. Some of the spores at 0° C. and at 10° C. retained the power of germination forty-nine days. It is evident that exposure to freezing temperature does not shorten the life of urediniospores. In Massachusetts the snapdragon remains green and lives through mild winters with no protection, and lives through harder winters if protected by a mulch. In January the writer obtained urediniospores from green plants growing outdoors in Massachusetts. These urediniospores germinated readily when placed at the optimum temperature for germination, but after these plants had been dried three weeks at room temperature the spores no longer germinated. Temperature is of less importance than drying in shortening the life of urediniospores.

To determine the effect of temperature on infection, twelve plants were sprayed with fresh spores distributed in distilled water. Four of these plants were placed at a temperature of 10° C., four at 15° C. and four at 18° C. The plants used were of a susceptible variety, Carter's Pink, but they were free from disease when selected, and from a disease-free bench. The plants remained in the above-mentioned temperatures twelve hours, after which they were all placed in the greenhouse at the same temperature.

Seven days later the stromata were visible. Ten days after inoculation the uredinia began to appear. One week later the number of sori on the plants was counted, with the results shown in Table 3.

TABLE 3. — *Effect of Temperature on the Infective Power of the Urediniospores of P. Antirrhini.*

Temperature at which Plants were inoculated.	Number of Sori per Plant.				Mean Infection in Relative Numbers.
	Plant A.	Plant B.	Plant C.	Plant D.	
10° C.,	240	265	210	180	100.0
15° C.,	9	6	15	20	7.6
18° C.,	5	3	7	9	3.5

It is thus seen that raising the temperature 5° to 8° C. above the optimum for germination of the urediniospores causes the amount of infection to fall off more than 90 per cent.

As a further test of the effect of temperature on infection of snapdragon by *P. Antirrhini*, plants of a susceptible variety were inoculated in two different greenhouses, having a night temperature of 10° C. in one case, and 15° C. in the other. Fifteen days after inoculation the plants in the greenhouse at 15° C. bore an average number of twelve uredinia, and the plants in the greenhouse at 10° C. bore an average number of one hundred and twenty uredinia.

As indicated by the results with *P. Antirrhini*, the rusts are able to germinate best at rather low temperatures. A consideration of the literature also supports this view. Erikson (1895) discovered that low temperatures are suitable to the germination of rust spores. He found that the spores of *Æcidium Berberidis* germinate best when cooled for seven hours to 3° C., and that the spores of *Peridermium strobi* germinate best when cooled for twenty-four hours to 6.5° C. He found the optimum temperature for the germination of the spores of *Uredo glumarum* to be 4.5° C., and that the spores of *Uredo coronata* germinate best after being cooled for sixteen hours to a temperature of —10° C. In the last case it seems probable that he went below the optimum temperature, and that the spores germinated when the temperature again rose to the optimum.

Howell (1890) found that the urediniospores of *Uromyces Trifolii* (Alb. and Schw.) Wint. germinate best between 11° and 16° C. They do not germinate below 7° C. nor above 21° to 25° C. If the minimum, optimum and maximum temperatures for germination of *U. Trifolii* are taken as 7° C., 11° C. and 21° C., respectively, this fungus has about the same temperature-germination relation as has *P. Antirrhini*, the minimum, optimum and maximum temperatures for germination of urediniospores of *P. Antirrhini* having been found by the writer to be 5° C., 10° C. and 20° C., respectively.

Experiments on Germination of Teliospores.

Numerous attempts to germinate teliospores were made with fresh material, dried material, teliospores produced under glass, teliospores produced outside, and teliospores wintered over outside. These germination tests were made at 7° C., 10° C., 12° C. and 20° C., but in no case did the teliospores germinate. These spores had formed in response to the definite stimulus of cold or drying. They do not germinate when first formed; they are spores of regeneration, and they may be considered as requiring a rest period, like other spores which function to carry fungi through adverse conditions. But these teliospores do not germinate after the rest period, that is, after passing the winter out of doors, when subjected to the range of temperature in which their host normally grows. It is not unlikely that they are killed by the cold, not being able to withstand the rigors of the winters to which their host has been carried.

Peltier (*loc. cit.*) reports that all efforts to germinate the teliospores failed.

The fact that teliospores do not germinate may be explained in another way. The temperature-germination curve for urediniospores is very sharp; and if teliospores have an even narrower range of temperature through which they can germinate, it is possible that the right temperature for germination has not yet been hit upon, since a variation a few degrees above or below the optimum temperature would result in no germination.

According to our present knowledge the teliospores are not only rare, but they do not germinate. This being the case, the possibility of an alternate host is eliminated. But no alternate host is necessary for a rust fungus which passes the winter under glass. The chrysanthemum rust fungus (*P. Chrysanthemi* Roze.) in America dispenses with both an alternate host and teliospores (Atkinson, 1890). Yet this rust occurs both in the greenhouse and out of doors, and persists from year to year. *P. Chrysanthemi* also is independent of the other rusts found on nearly related Compositæ, just as *P. Antirrhini* is not a parasite on other Scrophulariaceous plants, such as Linaria (see below, experiments with Linaria). Carnation rust, *Uromyces Caryophyllinus* (Schrank) Wint. has an alternate host, *Euphorbia gerardiana*, in Europe (Fischer, 1910), but it has not been found on an alternate host in this country. If the teliospores of *P. Antirrhini* ever were functional they seem now to be useless. The urediniospores of this fungus are sufficient to propagate it through the year, as long as greenhouses in the vicinity shelter the host plant during the winter. The urediniospore is a spore of dissemination. Spores of regeneration, such as teliospores, are not a necessity for a fungus the host of which occurs both under glass and out of doors.

The original host of *P. Antirrhini* is not known. Blasdale (*loc. cit.*) concluded that either snapdragon rust originated on the wild form of Antirrhinum (*A. vagans*), or its original host plant was not a member of the Scrophulariaceæ. Peltier (*loc. cit.*) made cross inoculations with

several species of Antirrhinum and with several species of Linaria, including *Linaria vulgaris* Mill. He obtained no infection on any species of Linaria. The only species of Antirrhinum except the cultivated snapdragon (*A. majus*) upon which he obtained infection was *A. maurandioides* Gray, in which case a few urediniospores were produced.

The writer made several attempts to infect *Linaria vulgaris* Mill. and *L. Cymbalaria* (L) Mill. by spraying the plants with water containing the urediniospores and placing them at the optimum temperature for their germination (10° C.). There was no infection whatever, although check plants of snapdragon similarly treated became badly rusted. It is unlikely that the rust occurs, at least in New England, on any other host plant than the cultivated snapdragon.

Dissemination.

Many growers take their cuttings at a time when snapdragon rust is at its height in the greenhouse, which is in March, April and May. There are various opinions as to the relative merits of raising plants from seeds and from cuttings, but plants raised from cuttings come true to color, and in the effort to preserve a good variety some growers take rust-free cuttings from a bench showing rust, or they take cuttings bearing spore pustules. Some growers have thought that if the cuttings show no spore pustules they are safe to use, even though they come from a bench of infected plants. The writer propagated plants by cuttings which bore uredinia and by cuttings which bore no uredinia, although taken from an infected bench. After three weeks all of the cuttings which bore uredinia were badly rusted, and 35 per cent of the cuttings which when made were apparently free from disease, although taken from an infected bench, showed the disease. It is evident, then, that cuttings bearing spore pustules may be expected to develop into rusted plants, and that cuttings free from spore pustules, if taken from a bench of infected plants, serve to aid very materially in the dissemination of the fungus. Microscopic examination of the leaf surfaces of these apparently healthy cuttings revealed numerous urediniospores which had fallen there or had been carried there from diseased plants. These spores need only the favorable environment of the cutting bench to cause them to germinate and infect the young plants, and it is therefore usually inadvisable to take cuttings from a house showing rust. Both Peltier (*loc. cit.*) and Stone (1917) consider cuttings as being among the principal means of dissemination.

Proof of the importance of greenhouse insects in the spread of snapdragon rust is not lacking. Three insects often found on snapdragon are the white fly (*Aleyrodes vaporariorum* West), the red spider (*Tetranychus bimaculatus* Harvey) and the common aphid (*Aphis gossypii*). With a binocular microscope the writer examined these insects on snapdragon foliage. They were on healthy plants, but there were rusted plants in the same bench. On the bodies of most of the insects examined were the urediniospores of *P. Antirrhini*.

The third agency by which the fungus is disseminated is watering. Carnation growers in watering make an effort not to wet the foliage any more than is necessary, usually employing a stiff piece of hose or pipe which enables them to get water into the middle of the bench without wetting the plants above. To this simple practice is due in part the decline in importance of carnation rust. The writer selected twenty snapdragon plants of the same variety, all showing uredinia in approximately equal numbers. Ten of these plants were watered only on the soil, no water touching the foliage. The other ten were treated the same, except that their foliage was kept wet. After three weeks the plants with wetted foliage showed 200 per cent more uredinia than they had at the beginning, while the plants whose foliage had been kept dry showed no increase in the number of uredinia. Water is necessary for the germination of the spores and for infection. A carelessly directed stream from a hose loosens spores from pustules, carries them to other plants, and provides them with the necessary moisture for their germination.

Pathological Anatomy.

The upper epidermis of the leaf and the palisade cells are only rarely affected by this disease. Occasionally a few palisade cells are forced apart by hyphæ. The spongy parenchyma cells are principally affected. The parenchyma cells in the immediate vicinity of a sorus do not attain their normal size. Strands of hyphæ force them apart and sometimes cause them to grow into abnormal forms. The chloroplasts fade slightly, but the yellow appearance of the area surrounding a sorus is due mostly to the presence of a stroma of mycelium. After the intercellular mycelium has become well established it develops this firm stroma in contact with the lower epidermis, and often includes scattered spongy parenchyma cells (see Fig. 5, Plate 2). This growing stroma and the rising pedicels of the urediniospores finally rupture the epidermis. The contents of cells containing haustoria do not degenerate unless the whole leaf becomes involved. Attacked cells do not swell, and any hypertrophy on the leaf is due to the development of stromata. Leaf cells of snapdragon which are normally pink lose this pigment when attacked by the fungus. When the sori occur on the stem the epidermis is ruptured, the cortical cells are forced apart, and in some cases the mycelium may be found between the cells of the fibro-vascular bundles. Ordinarily, however, cells as far in as the phloëm are not attacked. The chloroplasts fade even less in the stem than in the leaves. The cells of the cortex do not attain their normal size. Epidermal cells appear unchanged, though raised as a membrane above a sorus. Mycelium in both leaf and stem is local.

Varietal Susceptibility.

The list of commercially grown varieties of snapdragon, such as, for example, Nelrose, Silver Pink, Phelp's White and Keystone, is not large. But there is a large number of varieties listed and grown outdoors. Since there seemed to be but little information available as to which varieties are resistant and which susceptible, the writer tested forty-six varieties. The plants were grown from seed, and when the potted plants had reached a height of 6 inches they were inoculated by being sprayed with water in which urediniospores had been distributed, and placed under bell jars at 10° C. Each variety tested was represented by twelve to twenty individuals.

Two weeks after the date of inoculation the plants were examined and the number of rust pustules and infected leaves were counted. The plants were examined at weekly intervals for the next five weeks, and observations recorded as to the number of rust pustules and infected leaves. In the following table the varieties are grouped according to color, and under each color the most resistant varieties are named first, and the most susceptible varieties are named last, the intermediate varieties being so arranged that any variety is more resistant than those which follow it. Varieties equally resistant or susceptible are connected with brackets. By means of the relative numbers in the table it is possible to compare varieties of different colors as regards resistance.

Unfortunately, the most valuable commercial varieties, such as Nelrose and Silver Pink, are very susceptible to the rust.

The following table is perhaps not of great value to florists, since they must grow the varieties most in demand. But this table of relative susceptibility could be used as a basis in breeding resistant varieties, and by its use the amateur grower of snapdragons can avoid the more susceptible varieties, and still have a satisfactory garden of snapdragons.

TABLE 4.—*Relative Susceptibility of Antirrhinum Varieties to P. Antirrhini.*

Varieties.	Scale. Relative Numbers.	Varieties.	Scale. Relative Numbers.
White.		*Variegated or Mixed Colors.*	
Queen of the North,	0	Striped Variety,	0
Pure White,	0	Bronze Queen,	72
Giant White,	0	Niabe,	93
Phelp's White,	0	Fairy Queen,	93
Queen Victoria,	0	Carter's Gold Crest,	100
Mont Blanc,	0		
		Red.	
Yellow		Crimson,	0
Giant Yellow,	0	Giant Blood Red,	0
Hephaetos,	9	Fire Brand,	0
Dwarf Golden Queen,	100	Scarlet,	9
Sulphur Yellow,	100	Giant Scarlet,	16
		Dwarf Defiance,	23
Pink.		Giant Garnet,	23
Rose Dore,	0	Dark Scarlet,	37
Bridesmaid,	0	Half Dwarf Firebrand,	44
Giant Rose Pink,	23	Carter's Butterfly,	51
Rosy Morn,	30	Orange King,	58
Nelrose,	51	Black Prince,	58
Silver Pink,	51	Deep Crimson,	79
Dwarf Daphne,	65	Coral Red,	86
Rose,	86	Ruby,	100
Giant Pink,	86	Fiery Belt,	100
Dwarf Rose Queen,	93	Crimson Queen Victoria,	100
Carter's Pink,	100		
Delicate Rose,	100		
Venus,	100		
Chamois,	100		

Cause of Resistance.

Resistance of plants to disease has been explained in two general ways: (1) Resistance may be regarded as being related to certain morphological characteristics. Cobb (1892) considered resistance to fungous disease as being due to small stomata, waxy coating, and thick cuticle on the host. Freeman (1911) found that increase in bloom on barley leaves made the plants more resistant to rust. Valleau (1915) studied resistance of plums to brown rot, and considered resistance to be due to the pro-

duction of parenchymatous plugs which fill the stomatal cavity, and to lenticels composed of cork cells through which the hyphæ cannot penetrate. (2) On the other hand, the resistance of plants to disease has often been regarded as due not to morphological characteristics, but rather to physiological or chemical factors. Myoshi (1895) concluded that many fungi respond to chemical attraction. According to Massee (1904) infection depends on the presence of positive chemotactic substances in the plant cell. Klebahn (1896) concludes that infection is a kind of conflict between host and parasite. Bolley (1908) attributed resistance to chemical agents, such as toxins, which arise as a result of the fungous attack upon the host. These few citations from the extensive literature on this subject illustrate two views as to the resistance of plants to disease.

The work done by the writer indicates that the resistance of some varieties of snapdragons to rust is due to morphological characteristics rather than to physiological differences. The relative susceptibility of forty-six varieties of snapdragon to rust has already been given. The inoculated plants developed uredinia, some in large numbers and some in small numbers. But on both resistant and susceptible plants the sori were developed in the same length of time, and there was no apparent difference in the vigor of the sori after they had once broken through the epidermis. This seems to the writer to indicate that the difference in susceptibility is not due to chemical factors within the host cells, but rather to mechanical factors preventing infection. The most susceptible plant is the one infected in the most places, that is, the one into which the most germ tubes enter.

Infection of snapdragons by *P. Antirrhini* is always through the stomata. The writer sprayed urediniospores on the living leaves, and eight hours later examined the leaf surfaces microscopically. This was done repeatedly, but at no time was infection seen to occur anywhere except through the stomata. The plants used were kept in both light and darkness, with stomata both open and closed. The germ tubes were protruded, wandered about slightly, and then bent into the nearest stoma, or, if the water on the leaf dried too soon, they shriveled up and never reached a stoma. But no germ tubes were found which had penetrated or were penetrating the walls of the epidermal cells.

The mycelium within the leaf and stem is local; therefore the number of sori on a leaf or stem depends on the number of infections, and, since infection is only through the stomata, it was interesting to determine the connection between the number of uredinia (the index of relative susceptibility) and the number of stomata.

Leaves were taken from three-months-old snapdragons of susceptible and resistant varieties. The number of stomata on the upper epidermis per unit area of leaf was determined. In each case ten countings go to make up the average given for each variety. Ten susceptible and ten resistant varieties were used. The result of these counts is given in the following table: —

TABLE 5. — *Average Number of Stomata per Unit Area of Leaf.*

Susceptible Varieties.	Resistant Varieties.
3.1	1.5
4.1	1.5
3.0	2.0
2.0	1.0
3.0	1.3
3.3	1.6
3.0	1.1
2.8	1.7
5.0	1.1
3.2	1.8

The averages of these figures show that there are 3.25 stomata on the susceptible varieties to 1.46 stomata on the resistant varieties. Or, stated differently, the resistant varieties have only 45 per cent as many stomata as the susceptible varieties. The susceptible varieties showed approximately 200 per cent as many uredinia as the resistant varieties. This would indicate that in the snapdragon susceptibility is directly proportional to the number of stomata; that is, doubling the number of stomata doubles the number of uredinia or the amount of infection. Such a relation is, of course, relative rather than absolute.

It may be added that the stomata on resistant and susceptible varieties are present in the same numerical relation if both upper and lower epidermis are considered. The figures in Table 5 are for the upper epidermis only, because, owing to the fact that but little water clings to the lower epidermis, infection is mostly through the upper epidermis.

The stoma is the gateway through which the fungus enters. The fewer stomata there are, the fewer infections there will be, and the plant will appear correspondingly resistant.

CONTROL.

Laboratory Toxicity Tests with Copper Fungicides.

In all the toxicological experiments here described the general method used was that of Reddick and Wallace (1910). The fungicides used in these toxicity tests were prepared by Dr. O. R. Butler of the New Hampshire Agricultural Experiment Station. Glass slides were cleaned in potassium bichromate cleaning solution, rinsed in distilled water and dried between filter papers. The solution, the toxicity of which was to be tested, was sprayed on the slide by means of an atomizer, and the slides were then dried for twenty-four hours. Fresh urediniospores

were removed from living leaves by means of a stream of water from a pipette. These spores were shaken up in distilled water, drops of which were then placed on the sprayed and dried slides, and also on other unsprayed slides used as checks. This gives conditions similar to those the spores meet on sprayed and unsprayed leaves. The slides bearing the spores were then placed on culture plate benches in moist chambers, and these were placed at 10° C., the optimum temperature for the germination of urediniospores of *P. Antirrhini*. Here they remained for at least twelve hours, when the drops were examined microscopically, the spores counted, and the percentages of spores germinating determined. If there was no germination on the check (unsprayed) slides the results on the sprayed slides were of course discarded. At least three tests were made with each strength of solution. Only dilutions near the limit of toxicity are given in the tables, although stronger and weaker solutions were also used.

Copper sulfate was tested in dilutions ranging from .0039 to .25 per cent copper. The toxicity of copper sulfate is shown in the following table: —

TABLE 6. — *Effect of Various Strengths of Copper Sulfate on the Germination of Urediniospores of P. Antirrhini.*

PER CENT COPPER.	Germination relative to Check, 100.	Remarks.
0.25,	0	Mean of three experiments.
0.125,	5	Mean of three experiments.
0.0625,	5	Mean of three experiments.
0.0312,	12	Mean of three experiments.
0.0159,	18	Mean of three experiments.
0.0079,	14	Mean of three experiments.
0.0039,	24	Mean of three experiments.

It is thus seen that copper sulfate prevents germination of the urediniospores of *P. Antirrhini* at a strength of solution of 0.25 per cent copper. Melhus (1915) found copper sulfate toxic to the spores of *Phytophthora infestans* (Mont.) DeBary when the solution contained .0157 per cent copper. The indications are that the Uredinales are much more resistant to copper than are the Phycomycetes.

To determine the toxicity of copper sulfate to foliage of snapdragon, plants were sprayed with copper sulfate solutions containing from 0.25 to .0312 per cent copper. The sprayed plants were then dried slowly; that is, they were allowed to remain six hours in a moist chamber after spraying. The results are given in the following table: —

TABLE 7. — *Toxicity of Copper Sulfate Spray to the Foliage of Snapdragon.*

Per Cent Copper.	Injury to Foliage.
0.25,	Markedly injured.
0.125,	Markedly injured.
0.0625,	Slightly injured.
0.0312,	No injury.

It is evident from this that a copper sulfate solution which will prevent germination of urediniospores, a solution which must contain at least 0.25 per cent copper, is toxic to the foliage of the host. Copper sulfate therefore cannot be used as a control for snapdragon rust.

Cuprammonium sulfate (Eau celeste), $CuSO_4 . 4NH_3 . H_2O$, was the next fungicide tested. On drying, this gives rise to basic copper sulfate which on further weathering passes to copper sulfate. In these toxicity tests it was used in strengths of solution containing from 0.008 per cent to 0.5 per cent copper sulfate, with results shown in Table 8.

TABLE 8. — *Effect of Various Strengths of Cuprammonium Sulfate on the Germination of Urediniospores of P. Antirrhini.*

Per Cent Copper.	Germination relative to Check, 100.	Remarks.
0.1300,	0	Mean of three experiments.
0.0650,	0	Mean of three experiments.
0.0325,	4	Mean of three experiments.
0.0162,	22	Mean of three experiments.
0.008,	45	Mean of three experiments.

As here shown, a solution of cuprammonium sulfate containing 0.065 per cent copper prevents germination of urediniospores of *P. Antirrhini*.

The toxicity of this solution to the foliage of snapdragon was tested as in the case of copper sulfate. Solutions containing 0.25 or 0.125 per cent copper injured the foliage markedly, and a solution containing 0.065 per cent copper produced some injury. Cuprammonium sulfate at the strength toxic to the fungus is injurious to the host plant, and cannot therefore be used.

Other copper salts were not tested, for Melhus (*loc. cit.*) has found cupric sulfate ($CuSO_4 . 5H_2O$), cupric nitrate ($Cu(NO_3)_2 . 3H_2O$), cupric acetate ($Cu(C_2H_3O_2)_2 . H_2O$) and cupric chloride ($CuCl_2 . 2H_2O$) to be about equally toxic if they contain the same amounts of the toxic principle, — copper.

Hammond's Copper Solution, a commercial preparation which has been used by florists in attempts to control greenhouse rusts, was next tested. The stock solution as purchased was analyzed by Mr. T. O. Smith, assistant chemist at the New Hampshire Agricultural Experiment Station, and found to contain 0.018 gms. copper in 1 c.c. of solution. The manufacturers recommended that it be applied at the rate of 1 quart of the stock solution to 25 gallons of water, that is, a solution containing 0.018 per cent copper. The results of the tests are given in Table 9.

TABLE 9. — *Effect of Various Strengths of Hammond's Copper Solution on the Germination of the Urediniospores of P. Antirrhini.*

PER CENT COPPER.	Germination relative to Check, 100.	Remarks.
0.18,	5	Mean of three experiments.
0.144,	8	Mean of three experiments.
0.12,	19	Mean of three experiments.
0.072,	18	Mean of three experiments.
0.036,	17	Mean of three experiments.
0.014,	40	Mean of three experiments.
0.018,	72	Mean of three experiments.

It is evident that Hammond's Copper Solution, even when used at ten times the recommended strength, does not prevent germination of urediniospores of *P. Antirrhini*. In connection with this work the action of Hammond's Copper Solution on carnation rust was also tested, and at the recommended strength it was not toxic, the germination of the urediniospores of *U. Caryophyllinus* (Schrank) Wint. relative to check, 100, being 56.

Bordeaux mixture was next tested. The Bordeaux mixture used contained copper sulfate and calcium oxide in the approximate ratio of 1 : 0.3; that is, calcium oxide was added to slight alkalinity. This formula was used for the sake of convenience, but the same results would be obtained with any current formula, for the unit copper is equally toxic in acid, neutral and alkaline Bordeaux mixtures (Butler, 1915). The Bordeaux mixture used in the tests was diluted to various strengths, so as to contain the following percentages of copper sulfate: 0.0156, 0.0312, 0.0625, 0.125, 0.25, 0.5, 1, 2 and 4. The results are shown in Table 10.

TABLE 10. — *Effect of Various Strengths of Bordeaux Mixture 1 : 0.3 on the Germination of the Urediniospores of P. Antirrhini.*

Per Cent Copper Sulfate.	Per Cent Copper.	Germination relative to Check, 100.	Remarks.
4.0,	1.0	24	Mean of three experiments.
2.0,	0.5	25	Mean of three experiments.
1.0,	0.25	15	Mean of three experiments.
0.5,	0.125	32	Mean of three experiments.
0.25,	0.0625	33	Mean of three experiments.
0.125,	0.0312	23	Mean of three experiments.
0.0625,	0.0159	20	Mean of one experiment.
0.0312,	0.0079	20	Mean of three experiments.
0.0156,	0.0039	40	Mean of three experiments.

The urediniospores of *P. Antirrhini* are able to germinate in all the strengths of Bordeaux mixture employed by the writer. They germinate as readily in the mixture containing 1 per cent copper as in the mixture containing only 0.0039 per cent copper. There was a 10 per cent difference in favor of the weaker mixture, but this has no significance when we consider the irregular fluctuations shown by the intermediate strengths. It is probable that at the lesser strength the sprayed slide or leaf offers the maximum surface of solute to the solvent. An increased strength, as 1 per cent copper, means that the particles on the slide or leaf merely overlap each other, and do not offer an increased surface proportional to the added amount of substance. Having found a certain strength of Bordeaux mixture non-toxic to the urediniospores, increasing the strength of the Bordeaux mixture results in no toxic effect.

To confirm the results of the toxicity tests of Bordeaux mixture against *P. Antirrhini*, snapdragon plants all of the same variety were sprayed with Bordeaux mixture 1 : 0.3 containing 1 per cent copper sulfate. After spraying, the plants were allowed to dry, then with other plants of the same variety, not sprayed, were inoculated with snapdragon rust, the urediniospores being applied to the plants in distilled water by means of an atomizer. All inoculated plants, both sprayed and unsprayed, were then placed for twelve hours in an incubator at a constant temperature of 10° C., after which they were placed together in a greenhouse under the same conditions. Fifteen days after inoculation all the plants which had been inoculated were examined and the uredinia on the leaves were counted. The sprayed plants showed on the average two hundred uredinia each, while the unsprayed plants showed on the average two hundred and ten uredinia each; that is, there was an approximately equal amount of infection on the sprayed and unsprayed plants. Bor-

deaux mixture cannot, therefore, be recommended for the control of snapdragon rust. Peltier (1919) also came to the conclusion that Bordeaux mixture 4–4–50 will not control snapdragon rust.

Continuing the study of the toxicity of Bordeaux mixture to members of the Uredinales, the writer tested the effect of this fungicide on the germination of the urediniospores of carnation rust, *U. Caryophyllinus* (Schrank) Wint. It is realized that growers do not often spray for carnation rust now, being able to control this disease by cultural methods and varietal selection. But Bordeaux mixture has often been recommended for the control of this rust. Bordeaux mixture 1 : 0.3 was used in these tests in various strengths, so as to contain 0.5, 1, 2 and 4 per cent copper sulfate. The method employed was the same as that described for *P. Antirrhini*, except that the spores were germinated at 14° C., which temperature was found by the writer (Doran, 1919) to be the optimum temperature of germination for the urediniospores of *U. Caryophyllinus*. These urediniospores, like those of *P. Antirrhini*, germinated only when in contact with both air and water, spores in the interior of the drop of water never germinating.

The toxicity tests conducted by the writer showed that Bordeaux mixture is not toxic to the urediniospores of *U. Caryophyllinus*, which indicates that the behavior of the urediniospores of *P. Antirrhini* toward this fungicide is not exceptional. If carnation plants sprayed with Bordeaux mixture failed to rust, it must have been due to other adverse conditions, such as temperature, which prevented spore germination and infection.

It would appear from data obtained by others as well as from the results here reported that the Uredinales are much more tolerant of copper than are the Phycomycetes. Melhus (*loc. cit.*) found Bordeaux mixture toxic to *Phytophthora infestans* (Mont.) De Bary at 0.0039 per cent copper sulfate. But the writer did not find Bordeaux mixture toxic to the two members of the Uredinales studied at 4 per cent copper sulfate. It may be that the thick wall of the spore secretes some chemical substance which prevents the copper in the Bordeaux mixture from going into solution.

The literature contains numerous references to the use of copper solutions as a control of diseases produced by members of the Uredinales, but there is a variance of opinion as to the effectiveness of copper on rust diseases.

The experiments performed by earlier investigators were mostly of the field rather than the laboratory type. Dudley (1890) recommended a saturated solution of potassium permanganate as a control of hollyhock rust. Maynard (1893) found Bordeaux mixture to give good results as a control of carnation rust. Hitchcock and Carleton (1893) found the spores of *P. graminis* Pers. able to germinate in solutions of thirty chemical compounds of various strengths, including 0.1 per cent solutions of mercuric chloride, copper acetate, potassium bichromate, potassium

cyanide, acetic acid and sulfuric acid. Pammel (1893) attempted to control rusts on oats and wheat by spraying with Bordeaux mixture, but found no appreciable difference in the amount of the disease on the sprayed and unsprayed plants. Stuart (1894) found that Bordeaux mixture of standard and half strength solutions gave best results in the control of carnation rust. Bailey and Lodeman (1895) sprayed carnations with a mixture of Bordeaux mixture and soap. They also used a mixture of copper chloride, lime and soap. They concluded that the copper fungicides were most efficient in the control of carnation rust. Stewart (1896) recommended spraying with weak copper sulfate for the control of carnation rust. He found that the spores of *U. Caryophyllinus* can germinate in a copper sulfate solution containing 0.0025 per cent copper, and that there is slight germination in copper sulfate solutions containing as much as 0.083 per cent copper. He found these spores unable to germinate in 0.033 per cent solution of potassium sulfide. This investigator found that if copper sulfate is applied to carnation cuttings in a solution strong enough to control the rust the plants are injured. He found that Bordeaux mixture would not control carnation rust, and recommended spraying carnations with a 0.56 per cent copper sulfate solution, or with a 0.78 per cent solution of potassium sulfide. Sturgis (1896) recommended potassium permanganate for the control of hollyhock rust. Halstead (1897) sprayed hollyhocks with Bordeaux mixture, and found rust on all the check plots, while but one sprayed plot showed any rust. Kinney (1897) sprayed carnations with Bordeaux mixture, and concluded that this treatment did not control the rust. Abbey (1898) recommends Bordeaux mixture as an efficient fungicide in the control of chrysanthemum rust.

A survey of the literature on rust control by fungicides is not very helpful. Some of the statements made are misleading and few are very convincing; for instance, it is hard to see how potassium permanganate could be of any great value in combating a rust. Potassium permanganate destroys organisms by oxidizing them, and if in contact with oxidizable material it very soon loses its power; hence it would be of no avail against spores which subsequently fell upon the sprayed surface. Some investigators found Bordeaux mixture efficient and some found it inefficient as a fungicide for the control of rust. The narrow range of temperature in which the spores can germinate may have been exceeded, and the credit for no germination given to the fungicide instead of to a faulty temperature which reduces or prevents germination. But the literature does indicate that the rusts are very resistant to fungicides in general, especially to copper fungicides.

Sulfur Fungicides.

Dusting with sulfur has been used successfully as a control of *P. Asparagi* Dec. (Smith, 1905 and 1906). Butler (1917) described a sulfur dust control for rust of snapdragon. Stone (1917) recommended for the

control of snapdragon rust that plants be dusted with powdered sulfur every ten days, or sprayed with lime-sulfur 1 : 35.

The writer began his study of the toxicity of sulfur by testing the toxicity of sulfur applied in water. Powdered sulfur, washed and freed of sulfur dioxide, was added to drops of distilled water in which urediniospores of *P. Antirrhini* were placed. These spores in water with sulfur and the checks (spores in water without sulfur) were then placed at a temperature of 10° C. Subsequent examination showed that the spores in water with sulfur germinated quite as well as the spores in water without sulfur. This result is not surprising, for sulfur, being insoluble, would hardly be expected to have a fungicidal effect when applied in water. This result agrees with that of Melhus (*loc. cit.*), who found that the spores of *Phytophthora infestans* germinated as easily in water containing sulfur as in pure water.

The toxicity of dry sulfur to urediniospores of *P. Antirrhini* was next determined. Dry urediniospores were placed on slides and dusted with powdered sulfur. These were then put into desiccators and kept for three and one-half hours, some at a temperature of 12° C. and some at a temperature of 21° C., then placed in drops of distilled water and set away for twelve hours at their optimum temperature for germination, 10° C. They were accompanied by unsulfured spores as checks. The following table shows the relative germination of the spores sulfured at 12° C., and those sulfured at 21° C.: —

TABLE 11. *Effect of Dry Sulfur and Temperature of Application on the Germination of the Urediniospores.*

Germination of Spores exposed to Sulfur Three and One-Half Hours at the Temperatures stated. (Relative to Check, 100.)		Remarks.
12° C.	21° C.	
90.1	0	Mean of ten experiments.

It is thus shown that spores dusted with powdered sulfur and kept three and one-half hours at a temperature of 21° C. do not germinate. Spores similarly treated, but kept during the sulfuring at a lower temperature, 12° C., germinate as well as unsulfured spores. Sulfur at the lower temperature is comparatively inert, but at the higher temperature it reacts slowly with the oxygen of the air to form sulfur dioxide.

The experiment just described shows that sulfur as such is not toxic to the spores of this fungus. It is rather the sulfur dioxide generated by the exposure of dry sulfur to warm air that is toxic to the spores of the fungus. The more surface a substance exposes the more rapidly it reacts chemically. Hence the necessity of having finely divided, that is, finely powdered, sulfur rather than a coarser grade.

As a continuation of this experiment urediniospores were taken from snapdragon plants which had been dusted with powdered sulfur at a temperature not less than 21° C. These plants bore many spore pustules, and the fungus was to all appearances vigorous. But these spores failed to germinate when placed under optimum conditions for germination.

Fungine is a commercial preparation which has been used by some growers in their attempts to control snapdragon rust. As stated by the makers, it contains potassium polysulfide 6 per cent, and potassium thiosulfate 4 per cent. The writer tested the toxicity of this preparation to the spores of *U. Caryophyllinus* and of *P. Antirrhini* at various strengths and at the strength recommended by the makers. Fungine proved toxic to the spores of both of these fungi.

TABLE 12. — *Effect of Various Strengths of Fungine on the Germination of the Urediniospores of P. Antirrhini and of U. Caryophyllinus.*

Strength of Solution (Per Cent Thiosulfate).	Germination relative to Check, 100.		Remarks.
	P. Antirrhini.	U. Caryophyllinus.	
0.25, ...	0	0	Mean of four experiments.
0.50, ...	0	0	Mean of four experiments.
1.0, ...	0	0	Mean of four experiments.

Fungine, though toxic to the spores of these fungi, has certain disadvantages. It is no more efficient than powdered sulfur, but it costs more than the sulfur, and the sulfur dust reaches parts of the plant which a liquid spray would not. Fungine when sprayed on a slide or leaf has a physical character resembling a soap film, and this soapiness makes it wash off the leaf too easily, which may in part account for Peltier's conclusion (*loc. cit.*) that snapdragon rust in the field cannot be controlled by Fungine.

Temperature Regulation.

It has been shown that the urediniospores of *P. Antirrhini* cannot germinate below 5° C. nor above 20° C., and that they germinate best at 10° C. (50° F.); 50° F. is the night temperature at which the snapdragon is usually grown under glass; it is frequently grown in the house with carnations. This temperature results in a maximum amount of rust on the snapdragon. The carnation, on the other hand, is grown at a night temperature of 4° C. below the optimum for germination of the spores of carnation rust, and this may in part explain why carnation rust is so much less serious than snapdragon rust. Day temperatures of the houses are not important in the study of snapdragon rust, for those temperatures are usually too high for germination of the urediniospores, so we may consider infection as taking place only in the night.

If growers would raise or lower the night temperature of the snapdragon house to 52° F. or 48° F., the rust would decrease in amount about 50 per cent. This is indicated in the constant curve showing the relation between temperature and germination. It must be remembered that this temperature change prevents infections and prevents the spread of the disease, but it does not kill the spores. So if the temperature approaches the germination optimum even for a few hours, the disease may break out again. Rise of temperature as a control is further considered under treatment with sulfur. Growers may object to raising the temperature very much above 50° F. because of the danger of shortening the blossom spikes, but a rise of even two or three degrees will check the rust, and is not likely to diminish the value of the blossom spikes.

Selection of Resistant Varieties.

Forty-six varieties of snapdragon have been observed by the writer, and their relative resistance to *P. antirrhini* has been determined. The most susceptible varieties are Half Dwarf, Rose Queen, Fiery Belt, Crimson Queen Victoria, Ruby, Carter's Pink, Delicate Rose, Dwarf Golden Queen, Sulphur Yellow, Venus, Carter's Gold Crest and Chamois. It is recommended that the above varieties be not grown at all. The most resistant varieties are Queen of the North, Pure White, Rose Dore, Giant White, Crimson, Giant Blood Red, Giant Yellow, Striped Varieties, Hephætos, Phelp's White, White Queen Victoria, Firebrand and Mont Blanc. It is recommended that outdoor gardeners confine themselves principally to these varieties. These varieties, while not absolutely resistant, are the nearest approach to it among snapdragons. Florists grow only a few varieties, as a rule, notably, Keystone, Silver Pink, Buxton's Pink, Phelp's White and Nelrose. None of these varieties is really resistant. Florists can control this disease less by the selection of resistant varieties than can outdoor gardeners, but the florist can propagate from resistant individuals if any appear, and meanwhile safeguard his crop by the sulfur treatment.

Regulation of Moisture.

It has been shown that although temperature does not kill the urediniospores of *P. Antirrhini*, six weeks of drying does kill them. The teliospore may be eliminated as a factor; and as the urediniospores cannot germinate after six weeks of drying, there is no danger of the disease being transmitted on dry seed; also it is evidently impossible for urediniospores to live from season to season in a greenhouse if the snapdragons are removed and the house deprived of water for a period of at least eight weeks. A case of this kind has recently come to the attention of the writer. A house of snapdragons was severely attacked by rust last year. This year mignonette is being grown in the space occupied by last year's rusted snapdragons. Among the mignonette plants are many seedling snapdragons, the descendants of the rusted plants, but these

seedlings are absolutely clean and free from rust. Here we have a case of seed from infected plants producing seedlings free from disease, although they are growing in the space occupied by the diseased plants the previous year. Apparently their only protection is the drying out of the urediniospores.

Use of Fungicides.

The copper salts and copper mixtures, the toxicity of which to *P. Antirrhini* was tested in the laboratory, are copper sulfate, cuprammonium sulfate (Eau celeste), Bordeaux mixture (cupric sulfate to calcium oxide in the ratio of 1 to 0.3 present), and Hammond's Copper Solution. It is shown that Bordeaux mixture is absolutely useless for the control of this disease, for at no strength suitable for use on plants does it prevent germination, and sprayed plants when inoculated develop quite as much rust as plants similarly inoculated but not sprayed. The toxic constituent of Bordeaux mixture is copper sulfate, and this used alone has a toxic effect on the spores of *P. Antirrhini*, but in principle does not dissolve with sufficient rapidity to be efficient against either *P. Antirrhini* or *U. Caryophyllinus*.

Copper sulfate solution, 0.25 per cent copper, is toxic to the urediniospores of *P. Antirrhini*, but the use of this strength of copper sulfate on snapdragon is precluded because of its toxic effect on the foliage. Cuprammonium sulfate (Eau celeste) is toxic to the urediniospores of *P. Antirrhini* at 0.0625 per cent copper, but this strength of Eau celeste is liable to result in a toxic action to the foliage of snapdragon, unless the foliage can dry off in less than one hour. This nearly precludes the use of Eau celeste on thick crowded plants, for the bottom foliage would dry off too slowly. Eau celeste can be used only when the principle toxic to the foliage can be volatilized by rapid drying. Hammond's Copper Solution is not toxic to the urediniospores of *P. Antirrhini*, and is therefore of no use for the control of snapdragon rust.

A method for the control of snapdragon rust by dusting of the plants with sulfur has been described by Dr. O. R. Butler (1917). During the winter of 1916–17 the writer inspected, at intervals of two weeks, greenhouses of snapdragon which had been thus treated. When the treatment began the plants were in very bad shape, leaves and stems were fairly covered with rust pustules. The first thing done was to cut out those shoots so badly infected as to be hopeless. Many of them were girdled and dying. The sulfur used was obtained from the Union Sulphur Company and from Corona Chemical Company. It is powdered finely enough to pass through a sieve having 40,000 holes to the square inch. It was applied with a good bellows that filled the air of the greenhouse with dust, which settled as a thin even film on the foliage. For plants 10 inches high, 4 ounces of sulfur were applied to 150 square feet of bench. The sulfuring was repeated at intervals of two to three weeks, as necessitated by new growth of plants. Exposed blossoms were injured, but there was no injury to the leaves. For two days after sulfuring the night

temperature was kept between 60° F. and 70° F. Spores from these sulfured plants were tested from time to time and were uniformly unable to germinate. The mycelium in the plant remained alive, and occasionally produced new sori near the old ones. But new infections were impossible, and the spread of the disease was checked. In one case some young plants which had been sulfured became infected, but the explanation was soon found. They had been grown since sulfuring at a temperature not over 50° F. To be successful, the sulfur must be accompanied by some rise of temperature.

Fungine, a potassium polysulfide preparation, is toxic to the urediniospores of *P. Antirrhini*. It controls snapdragon rust under glass if applied to the plant frequently, but its use is not recommended, for it has no advantages over powdered sulfur, while it costs more and cannot be applied as thoroughly as a dust.

Summary of Control Measures.

Many of the experiments already described contain suggestions as to the control of snapdragon rust. They may be summed up as follows: —

1. There is only very slight chance of rust entering a house on the seeds. The urediniospores would not live on the seeds. Teliospores are not formed till after seed is harvested, and are of no use to the fungus when formed.

2. A house which has contained snapdragon rust should not be used for snapdragons the following year if any plants have remained alive during the interim, nor unless the house has been dried out.

3. Cuttings should not be taken from a bench showing rust. If such cuttings must be used, dust them with powdered sulfur, and give them a high temperature for a few nights.

4. Varieties showing resistance to rust should be selected. The list of varieties showing relative susceptibility should be of assistance here.

5. Water should be kept off snapdragon foliage. In watering, only the soil should be wet. If syringing becomes necessary it should be done on a sunny morning so that the foliage will dry off quickly.

6. Insects should be kept down; they serve to spread the rust. But cyanide must be used carefully, as snapdragons are easily injured by it.

7. If rust appears the plants should be dusted with finely powdered sulfur. If only a few isolated leaves are infected they should be removed by hand picking. The sulfur should be applied with a good bellows that will throw clouds of dust. The temperature should be kept up for a few nights. (For more detail on sulfuring, see the article by Dr. O. R. Butler, 1917.)

8. A solution of cuprammonium sulfate containing 0.065 per cent copper will control the fungus, but because of its toxic effect on the foliage it can be used with safety only when the sprayed foliage will dry within one hour.

9. Bordeaux mixture is absolutely ineffective.

10. If rust appears the temperature should be run up to 60° F. at night for a few nights, till the rust has been placed under control by sulfuring or hand picking. It should be borne in mind that 50° F. is the temperature most favorable to the fungus.

Summary.

Puccinia Antirrhini Diet. and Holw. is known to occur only on *Antirrhinum majus*.

This rust is the most serious disease of snapdragons under glass, and is second in importance to anthracnose on snapdragons out of doors.

The urediniospores germinate moderately well with an optimum temperature of 10° C.; the teliospores have not been germinated.

Dry urediniospores do not retain the power of germination more than six weeks.

No varieties of snapdragon are absolutely resistant to the parasite, but some are relatively resistant. The varietal resistance is dependent on the relative number of stomata per unit area of leaf surface.

The urediniospores are disseminated by cuttings, insects, water and wind.

A 0.25 per cent solution of copper sulfate is toxic to the urediniospores of *P. Antirrhini*.

A 0.25 per cent solution of cuprammonium sulfate is toxic to the urediniospores of *P. Antirrhini*.

Bordeaux mixture is not toxic to the urediniospores of *P. Antirrhini*.

The SO_2 generated by dry sulfur at a temperature of 21° C. is toxic to the urediniospores of *P. Antirrhini*.

The method of control recommended consists in growing resistant varieties, controlling cultural conditions carefully, dusting with powdered sulfur at a temperature of 70° F., and keeping the night temperature of the snapdragon house above 52° F. or below 48° F.

Literature Cited.

Atkinson, G. F., 1890. Chrysanthemum Rust. Botanical Gazette, 15: 166.

Howell, J. K., 1890. The Clover Rust. Bull. 92, N. Y. (Cornell) Agr. Expt. Sta., pp. 127–139. 8 figs.

Cobb, N. A., 1892. Contributions to the Economic Knowledge of the Australian Uredineæ. Agr. Gaz., New South Wales, 3 (3): 181, 182.

Maynard, S. T., 1893. Carnation Rust. Hatch Expt. Sta., Mass. Agr. College Rept. for 1892, pp. 157, 158.

Hitchcock, A. S., and Carleton, M. A., 1893. Preliminary Report on Rusts of Grain. Bull. 38, Kans. Agr. Expt. Sta., pp. 1–14. Pls. 1–3.

Pammel, L. H., 1893. Experiments with Fungicides. Bull. 24, Iowa Agr. Expt. Sta., pp. 985–990.

Stuart, W., 1894. Carnation Rust. American Florist, 9: 1231, 1232.

Bailey, L. H., and Lodeman, E. G., 1895. Forcing House Miscellanies. Bull. 96, N. Y. (Cornell) Agr. Expt. Sta., pp. 294–335.

Erikson, J., 1895. Ueber die Forderung der Pilze poren Keimung durch Kalte. Cntr. F. Bact., 2: 557–565.

Sturgis, W. C., 1896. Miscellaneous Notes on Various Fungous Diseases. Conn. Agr. Expt. Sta. Rept. for 1895, pp. 185–189.

Stewart, F. C., 1896. Experiments in the Treatment of Carnation Rust. Florists' Exchange, 8: 167, 168.

Stewart, F. C., 1896. Combating Carnation Rust. Bull. 100, N. Y. (Geneva) Agr. Expt. Sta., pp. 33–68. 2 figs.

Halstead, B. D., 1897. The Carnation Rust. N. J. Agr. Expt. Sta. Rept. for 1896, pp. 289–430.

Kinney, L. F., 1897. The Carnation Rust. R. I. Agr. Expt. Sta. Rept. for 1896, pp. 207–210. 2 figs.

Abbey, G., 1898. Chrysanthemum Rust. Journal of Horticulture, 50: 284, 285.

Dietel, P., 1899. Einige neue Uredineen. Hedwigia, 36: 298.

Stewart, F. C., 1900. Anthracnose and Stem Rot of Snapdragon. Bull. 179, N. Y. (Geneva) Agr. Expt. Sta., pp. 104-114. Pls. 3.

Blasdale, W. C., 1903. On Rust of the Cultivated Snapdragon. Jour. Mycol., 9: 81, 82.

Smith, R. E., 1905. Asparagus and Asparagus Rust in California. Bull. 165, Cal. Agr. Expt. Sta., pp. 1–99. 46 figs.

Smith, R. E., 1906. Further Experience in Asparagus Rust Control. Bull. 172, Cal. Agr. Expt. Sta., pp 1–21. 7 figs.

Bolley, H. L., 1908. The Constancy of Mutants; the Origin of Disease Resistance in Plants. Proc. American Breeders Assoc., 4: 121–129.

Fischer, E., 1910. Die Zusammengehorigkeit von *Aecidium Euphorbiae-Gerardiana* Fischer und *Uromyces Caryophyllinus* (Schrank) Winter. Centr. F. Bact., 28: 139.

Reddick, D., and Wallace, E., 1910. On a Laboratory Method of Determining the Fungicidal Value of a Spray Mixture or Solution. Science, N. S., 31–198.

Freeman, E. M., 1911. Resistance and Immunity in Plant Diseases. Phytopathology, 1 (4): 109–115.

Peltier, G. L., and Rees, C. C., 1914. A New Rust of Economic Importance on the Cultivated Snapdragon. Phytopathology, 4 (6): 400.

Rees, C. C., 1914. Rust on Antirrhinum. American Florist, 43: 1198.

Nehrling, A. H., 1914. Timely Hints on Three Minor Crops of the Florist. Facts for Farmers, 4 (12), pp. 1–4, Mass. Agr. Ext. Serv.

Butler, O., 1915. Methods of Preparation and Relative Values of Bordeaux Mixtures. Sci. Contribution 9, N. H. Agr. Expt. Sta., pp. 1–12.

Melhus, I. E., 1915. Germination and Infection with the Fungus of Late Blight of Potato. Res. Bull. 37, Wis. Agr. Expt. Sta., pp. 1–64. 8 figs.

Valleau, W. D., 1915. Varietal Resistance of Plums to Brown Rot. Journ. Agr. Res., 5 (9): 365–395. Pls. 37–39.

Bailey, F. D., 1915. Second Bien. Crop Pest and Hort. Rept. Ore. Agr. Expt. Sta. (1913–14), p. 281.

Clinton, G. P., 1915. Notes on Plant Diseases of Connecticut. Part VI of the Annual Rept. of 1915 of the Conn. Agr. Expt. Sta., pp. 443, 444. Pl. XXIII *c*.

Butler, O. R., 1917. How to Control the Snapdragon Rust. Florists' Exchange, 43: 353.

Doran, W. L., 1917. Controlling Snapdragon Rust; Value of Copper and Sulphur. Florists' Exchange, 43: 501.

Stone, R. E., 1918. Plant Diseases in Ontario. Ann. Rept. Ontario Agr. College and Expt. Farm, 43 (1917): 20–31.

Guba, E. F., and Anderson, P. J., 1919. Phyllosticta Leaf Spot and Damping-off of Snapdragons. Phytopathology, 9: 315–325. 8 figs.

Thurston, H. W., Jr., 1919. Puccinia antirrhini. Phytopathology, 9: 330.

Doran, W. L., 1919. The Minimum, Optimum and Maximum Temperature of Spore Germination in some Uredinales. Phytopathology, 9: 391–402. 1 fig.

Peltier, G. L., 1919. Snapdragon Rust. Bull. 221, Ill. Agr. Expt. Sta., pp. 535–548. 5 figs.

BULLETIN No. 203.

DEPARTMENT OF BOTANY.

TOBACCO WILDFIRE.

PRELIMINARY REPORT OF INVESTIGATIONS.

BY G. H. CHAPMAN AND P. J. ANDERSON.

INTRODUCTION.

Wildfire is the name of a bacterial disease of tobacco which was first reported in 1916 in North Carolina. It may possibly have been present in previous years, but was not noted until Wolf and Foster (4) described the trouble in that year, when it caused losses in some fields. Since 1916 it has been found in a number of the tobacco sections of the country, more particularly in Kentucky, Virginia and South Carolina. It was first noted in Connecticut in 1919, but was not reported in any amount until 1920, when Dr. Clinton of the Connecticut Agricultural Experiment Station found it to be serious locally. During the same season it was found in three localities in Massachusetts.

In 1921 a very serious seed-bed infection was reported from both Connecticut and Massachusetts, and at a somewhat later date the disease was also reported from seed-beds in Pennsylvania and Ohio.[1] The disease has not been serious in the South this year, but in Massachusetts and Connecticut there was not only a wide seed-bed distribution, but also severe infection, particularly in the broadleaf, where diseased plants were set in the field. It is estimated that in Massachusetts approximately 20 per cent of the seed-beds, including those of all types of tobacco, had more or less wildfire infection. In some cases there was only a slight infection, and in others up to 90 per cent of the seedlings were infected.

The importance of the disease to the tobacco industry is great because leaves which are badly spotted are practically valueless; and furthermore, in the fields the infection works from the bottom of the plant towards the top, as a rule, and the best-quality leaves are the ones first infected.

[1] Plant Disease Bulletin, 5: 19, 37. 1921.

Last year, when to the best of our knowledge the disease appeared in rather widely separated localities in Massachusetts, it was felt that the spread might not be rapid, but in 1921 the infection was quite general throughout the State, with apparently local centers of heavy infection, the only beds or sections free from the trouble being those in outlying districts.

Unless the disease is controlled there is no question but that it will become a serious matter and the cause of considerable loss to the tobacco growers. It is apparent from data collected this year that nearly all, if not all, of our field infections originate in the seed-beds; hence the production of healthy seedlings becomes a matter of prime importance.

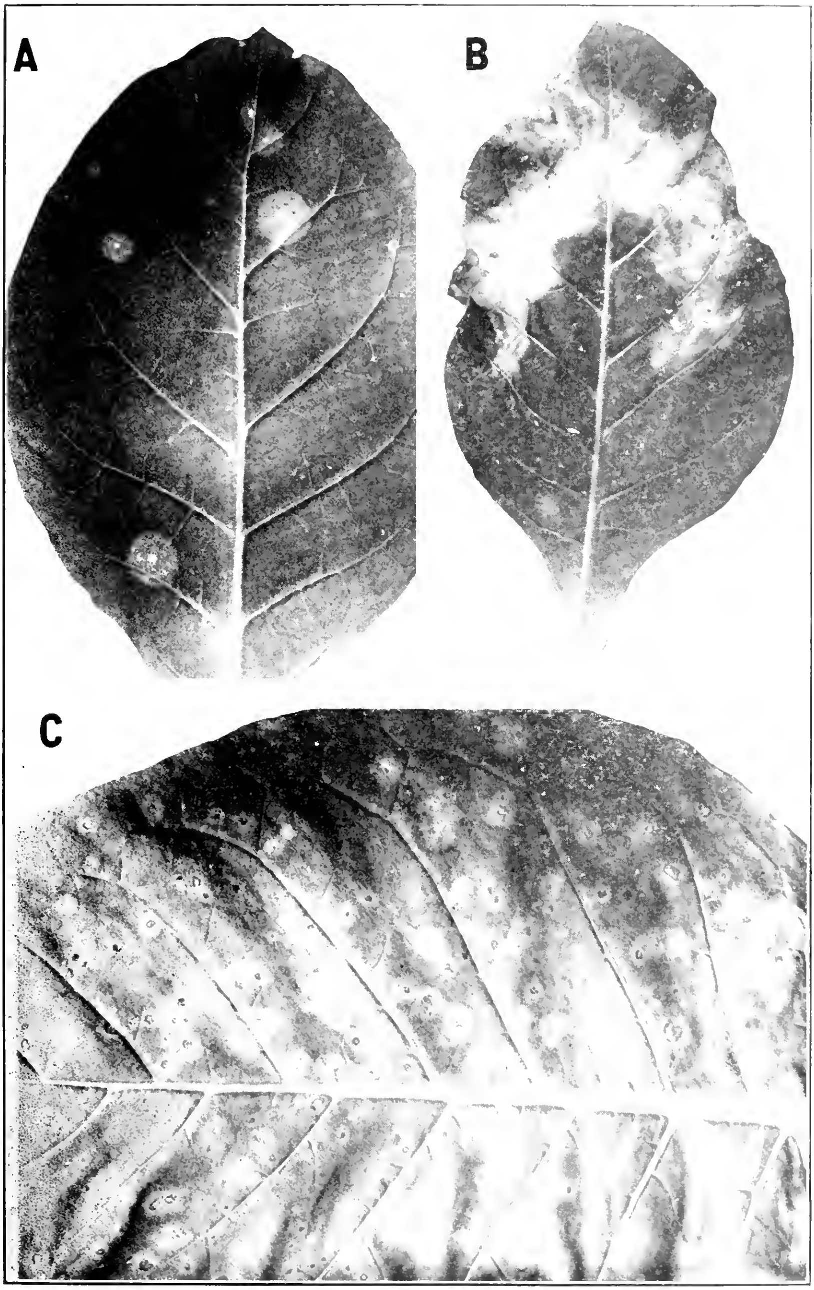
Weather conditions have a great deal to do with the spread of the trouble, as has been shown not only in the South but in Massachusetts as well. But even under favorable conditions timely control measures are necessary to combat the trouble.

It is not known how in 1921 wildfire became so generally distributed throughout the different sections, nor why we apparently had two or three successive infections during the seed-bed period. In order to determine these points, and to find, if possible, some methods of prevention, eradication or control, investigations were begun by the writers in the spring of 1921. These investigations are by no means completed, but sufficient data, especially on seed-bed control, have been secured to warrant a preliminary report.

APPEARANCE OF THE DISEASE.

The symptoms or signs of the disease are prominent and very easily recognized. The spots may be found on the leaves at any stage in the development of the plant from the time the first seed-leaves appear to full maturity. They are sometimes found on the seed-pods, but have not been observed on stalks or roots. They are usually noticed first in the seed-bed. The typical spot on the leaf in its first recognizable stage is a circular chlorotic area, yellowish green, of a lighter color than the surrounding leaf surface, and less than a quarter of an inch in diameter. Within the next twenty-four hours a small brown or whitish dead speck of less than pin-head size marks the center of the lesion which, under conditions favorable for the disease, has now increased to a quarter of an inch or more, is of a more decided yellow color, and forms a prominent halo about the central dead area (Plate I, Fig A). Both the central brown dead spot and the yellow halo now increase in size, and within a few days the affected part may be a half inch or more in diameter. The central brown dead part may or may not be surrounded by a water-soaked translucent band, depending apparently on moisture conditions. In very humid times the entire spot is sometimes soft and water-soaked. The most constant and dependable character is the yellow halo which persists in all stages of development. Any number of spots may occur

PLATE I.



SYMPTOMS OF WILDFIRE

A. Infection of four days, showing typical halo spots with pinhead centers

B. Multiple infections coalescing and causing distortion of leaf

C. Typical infection of leaf in field seven days after heavy rain

on a single leaf (Plate I, Fig. C), and when numerous they usually run together to produce large irregular dead areas. Frequently, when a leaf is attacked while it is rapidly developing, the affected part becomes distorted and uneven (Plate I, Fig. B). Spots may be located on any part of the leaf, but a great number of them are marginal with a semi-circular halo. During dry weather the dead areas remain intact, but in stormy weather they may be broken out and result in a ragged appearance of the leaf. Severely attacked plants, especially in the seedling stage, may die, but more often the plant continues to grow and is only stunted by the injury or loss of a part of its leaves. In the field the lower leaves are most affected. No lesions are found at the top of the plant on the very young leaves which are just unfolding. Badly affected leaves are practically worthless on the market, as they cannot be used for wrappers or binders.

In the very early seedling stage, when the plants are no larger than the thumb nail, the symptoms may be atypical and not readily recognized as wildfire by the inexperienced. Superficially, affected plants have much the appearance of being attacked by ordinary damping-off. The leaves are usually affected from the margins inward and the lesions are more typical of a wet rot, and in this condition the water-soaked, translucent line is particularly noticeable between the living and dead tissue. Very often the entire leaf is withered, and nothing but the dried midrib is observable. In such plants the stem, however, is usually not affected, and this character differentiates the trouble from the ordinary damping-off, for in the latter disease infection starts in the stem and the entire plant rots down.

CAUSE OF WILDFIRE.

When the disease first came under investigation in North Carolina, Wolf and Foster (4) demonstrated by isolations and inoculations that it is produced by a parasitic species of bacteria which they named *Bacterium tobacum*. In Massachusetts the writers have made numerous isolations from all the types of lesions described above, and have invariably obtained pure cultures of an organism which gave the same cultural tests as described by Wolf and Foster (5). The same organism has never failed to produce the typical disease when healthy plants were inoculated with it from pure cultures.

An individual bacterium of this species is so microscopically small ($3.3 \times 1.2\mu$) that over 7,500 of them placed end to end would form a chain only one inch long. Its body is cylindrical with rounded ends, and two or three times as long as broad. In fresh cultures the organisms may be seen under the microscope actively darting about, the motion being produced by vibrating the long tail-like flagella (1 to 4 in number) which are attached to one end of the body. The body increases in length and divides into two individuals by the process of fission. After repeated division short chains of bacteria may be observed before they break apart.

Life History of the Causal Organism.

Although there is very little to learn about the structure of this very simple organism, there are many things which it is important that we should know about its life history. Control measures can be developed only after determining important life-history facts, such as the manner and place of overwintering, method of entrance to host, methods of spreading in the seed-bed and in the field, and longevity of the organism in various environments. About some of these life-history phases little or nothing is known as yet; concerning others we now have more definite information. It is hoped that experiments now in progress, but not completed at the date of issue of this bulletin, will clear up some of the places in the life history about which we are now ignorant. At this time we can only summarize the progress which has been made up to the present by investigators in other States, and by the writers in Massachusetts.

Infection. — Infection may occur at any stage in the development of the tobacco plant. The bacteria thrive and cause injury by rapid propagation inside the tissues of the leaf. The method by which they pass from outside the leaf through the epidermis into the interior tissue is not yet definitely known. The only openings through which they can pass are the stomates (breathing pores), the hydathodes (openings on the margins of the leaves for the exudation of water), and accidental abrasions or wounds. The writers have frequently demonstrated, however, that visible wounds are not necessary. Healthy plants of various ages have been inoculated by spraying with a suspension of the bacteria in water. Almost without exception infection has resulted, although the most careful examination has failed to reveal any wounds in the leaves. If the stomates were the only avenues of entrance, one would expect a greater percentage of infection when the lower surface of the leaves was inoculated, but the amount of infection has been about the same, irrespective of whether the upper or lower side was inoculated. The rather high percentage of marginal infection points toward the hydathodes as important infection courts. Moisture has an important role to play in infection, although perhaps more important in dissemination. Infection occurs in the field principally during rainy periods. It is not essential that the water should remain on the leaves for any long time. Successful infections are secured by spraying water suspensions on the leaves even when they become dry within a few hours.

Incubation Period. — This period covers the time between the passage of the bacteria into the interior tissues and the appearance of the first symptom of disease. The length of this period as determined by carefully watched experiments at this station is three to eight days. In the field growers usually begin to notice increased infection in five to seven days after a rain, but since the first symptoms are inconspicuous, and the casual observer does not notice the spots until they have been developing

for two or three days, this confirms our conclusion as to the length of the period.

According to Wolf and Foster (5) the bacteria at first propagate only between the cells of the leaf. The cells soon begin to collapse, and one finds not only the intercellular spaces, but the cells themselves filled with dense masses of bacteria. Enzymes secreted by the bacteria apparently break down the cell contents, and some of the decomposition products are used as food for further multiplication of the parasites. As the tissue collapses the bacteria either ooze out to the surface or are exposed by rupture of the epidermis.

Dissemination.

This disease was called "wildfire" because of the extreme rapidity with which it spreads. It has been noted by all investigators of the disease and by tobacco growers that rapid spread invariably follows heavy rains. When the rain drops fall on the diseased spots, the bacteria float out into the water and successive drops splash them to other leaves of the same plant or to neighboring plants. If the rain is accompanied by wind the drops are carried farther and the spread is greater to the windward of diseased plants. A number of cases have been observed by the writers where the spread from a single diseased plant or diseased row resulting from wind-driven rain has been carefully followed. Invariably the area of new infection has been from two to ten times as great to windward as to leeward. These two agents (wind and rain) are undoubtedly the most potent of all the factors involved in dissemination. A number of experiments with various agents suspected of disseminating the disease have been conducted at this station and are summarized below.

Splashing Rain. — In order to corroborate field observations, dropping water from a rose nozzle in the greenhouse was allowed to fall onto diseased leaves and then splash to healthy young plants. The splashing was continued for five hours. Wind, insects and all other agents were excluded. Within five days lesions were observed on the plants where the water had splashed. Check plants in the same bed, which were separated from the splashed plants only by a glass partition and which had been splashed with uncontaminated tap water at the same time, remained entirely healthy. The results confirm in every way the conclusion from field observations that this is a very important agent of dissemination.

Wind. — That wind may be important in carrying the infested rain drops to greater distances has been previously mentioned and needs no further demonstration. But on the other hand, it seemed to be important to determine whether wind alone, without rain, could carry the bacteria from a diseased to a healthy plant. Therefore five diseased plants in pots were placed before an electric fan, and twelve healthy potted plants set at distances ranging from three to twenty-four inches, so placed that the air current passed from the diseased to the healthy plants. The fan was turned on for three hours on four successive days, the plants were sprinkled

between times and kept under favorable conditions for infection. Since no infection resulted, even after several weeks, it seemed apparent that wind alone cannot spread the disease.

Leaf Contact. — Since in the seed-bed, and to some extent in the field, the leaves of adjacent plants come into contact, it seemed possible that the bacteria might thus pass from a diseased to a healthy plant. In order to determine whether this is possible, two diseased plants in pots were placed under a closed bell jar with two healthy plants in such a position that healthy leaves were in contact with diseased leaves in a natural way without any device for keeping them together. They were not watered, but moisture soon accumulated inside the bell jar. In a second bell jar the same experiment was repeated, but the jar was open at the top except for a thin piece of cheesecloth used to exclude insects. Infections resulted in both cases. There can be no question then but that wildfire may spread by contact. This factor is probably of more importance in seed-bed dissemination than in the field. When plants have been pulled and piled together in boxes or baskets until ready to be set in the field the moisture conditions are very favorable for the spread of the disease to healthy plants. Occasionally such plants are kept thus for days before planting, and, if diseased plants are present, no better opportunity for spreading wildfire by contact could be found.

Handling by Workmen. — Do workmen, in weeding, transplanting, hoeing, plowing and topping help to spread the disease? In order to answer this question diseased leaves were crushed between the fingers and then leaves of a healthy plant drawn through the fingers without rupturing the leaves. The plants were then kept protected under a bell jar. A few of the leaves thus treated developed typical lesions of the disease. Check plants treated in the same way after healthy leaves had been crushed in the hand remained free from disease. There is no doubt, then, that wildfire may be spread by workmen during the ordinary manipulations of the crop. The danger of spread is much greater while the plants are wet, and if there is any disease at all present, all operations while water is on the leaves should be avoided.

Insects. — It would seem almost impossible for insects to work alternately on diseased and healthy leaves without spreading the bacteria. Wolf and Moss (6) state that "flea beetles are to be regarded as carriers of infection, since the wildfire organism has been isolated from individuals which had been feeding on diseased plants." Flea beetles were the most common insects found on tobacco both in seed-bed and field in this State during the present year, and it was suspected that they carried the bacteria. To determine whether such was the case, large numbers of flea beetles were caged with diseased plants; then, after they had fed on these plants for several days, they were transferred to healthy plants, where they riddled the leaves. No wildfire lesions ever developed on these plants. Thinking that possibly the beetles had not eaten from the diseased spots in the infected plants the writers caged another lot in tubes in which only

diseased bits of leaves were placed. Most of the diseased pieces were entirely consumed and all of them more or less eaten. The insects were then transferred to cages in which healthy plants were growing. Although numerous holes were eaten through the leaves, no wildfire lesions developed. The flea beetle experiments variously modified were repeated five times, but always with negative results. Wolf and Foster (5) had the same results with thrips. Other insects have not been found on tobacco in sufficient numbers to indicate that they could be the agents of dissemination. From all evidence which has been secured up to the present time we may conclude that insects are of little or no importance in the spread of the disease. This conclusion is also corroborated by a study of field conditions. If insects were responsible, one would expect to find scattered throughout the field plants which had only one or a few infections on the upper leaves, and spread from a single infected plant would be more rapid. But such is not the case. As will be explained below, most of the infections can be traced from the lower leaves, and can be readily explained by splashing and wind-borne rain.

Origin of the Disease in the Seed-beds.

Wildfire makes its first appearance in the seed-beds when the plants are yet very small. It is very essential that we should know the source of the bacteria which start this initial infection. This involves the whole problem of the overwintering of the bacteria. The possibilities are that the bacteria pass the winter on (1) the seed, (2) the chaff with the seed, (3) in the soil, (4) in the sash, frames, covers, etc. Experiments are now in progress to solve this problem by determining the longevity of the bacteria in various environments, but since these experiments have not as yet reached their conclusion, nothing can be stated as demonstrated. Fromme (2) in Virginia believes that the bacteria overwinter with the seed. The fact that infections are not positively known to start in the field from soil which is splashed onto the leaves leads one to suspect that the soil is not the source of early infection in Massachusetts. In North Carolina, however, Wolf and Moss (6) found that soil or the cloth covers which had been used the previous season could serve as carriers in overwintering the bacteria. We expect to have more definite information in regard to this point before next season. When once started in the bed, the bacteria are easily spread by splashing during watering, contact of plants, weeding, etc.

Source of Infection in the Field.

Careful field observations have been made during the past season on the origin of the field infections and the spread in the field. In the vast majority of cases it has been found that the plants came from infested seed-beds, and in all other cases the seed-bed has been suspected, but it has not been possible always to prove that it was the source. Almost always, throughout the season, when a diseased plant was found the spots

could also be found on the lower leaves of the same plant which were present when the plant was set out. If not on the same plant, then they could be found on a plant which was very close by. In all the field observations we have seen nothing to indicate any other independent source of the inoculum.

OTHER HOSTS.

Up to the present the causal organism of wildfire has been found actively parasitic only on tobacco. The possibility is not excluded, however, that it may occur on other hosts. Wolf and Foster (5) isolated the organism from spots on cow peas, and were able to produce the typical disease on tobacco with the strain taken from cow peas. Only occasional small spots developed on inoculated cow peas, and they are of the opinion that the organism is not parasitic on this host, but developed only in the weakened tissues about injuries produced by leaf hoppers. They also inoculated bell peppers, potatoes, tomatoes, eggplants, horse nettle and jimson weed but were unable to produce the disease.

The writers have inoculated petunia, eggplant and pokeweed (*Phytolacca decandra*) by spraying them with suspensions of bacteria in water in the same way in which tobacco plants were usually inoculated. Some of the leaves in each case were wounded by punctures with a sterile needle.

Petunia. — Within four days after inoculation typical wildfire lesions appeared about all the punctures and on some of the leaves where no punctures were made. These increased to the usual size and the centers died. Reisolations gave the organism in pure culture, and, when tobacco plants were inoculated from these cultures, wildfire resulted. The tobacco wildfire organism is thus parasitic on the closely related genus Petunia.

Eggplant. — These plants were kept under humid conditions in bell jars. After six days necrotic lesions developed about all the punctures, but none where punctures had not been made. The lesions were 5 to 10 millimeters in diameter. Thus, although the bacteria are able to spread from wounds, apparently they are not actively parasitic on eggplant.

Pokeweed. — After a week a few lesions developed about the punctures and showed the typical broad halo. Parasitism is thus about the same as on eggplant.

Tomato. — While examining a seed-bed of infected tobacco plants at Southwick, the writers found lesions of the same type on some tomato plants which were growing among the diseased tobacco seedlings. Microscopic examination showed bacteria of the same kind in the lesions, and pure cultures were obtained. Tobacco plants inoculated from these cultures developed typical wildfire lesions. The spots on the tomato leaves appeared to have started around injuries of some kind. Undoubtedly, however, the bacteria were able under natural conditions to spread from these wounds into healthy tissue.

Further investigations of host relationships are in progress. Probably the same species of bacteria does not cause a serious disease of any of our

common plants, yet it may occur rather commonly in a semi-parasitic inconspicuous condition, and this fact may prove to be of some importance in the dissemination or overwintering of the organism, and thus indirectly, also, in the control of wildfire.

CONTROL.

Necessity of starting with the Seed-bed.

It has been shown that nearly every field infection originates in the seed-bed, and that as yet there is no positive evidence that the disease has originated in the field, at least in Massachusetts. In every case that came to our attention where healthy seedlings were set, no infection was found except that brought in afterward by partial resetting. Therefore it is evident that if the seed-beds can be kept free from disease, the fields will be free from it also. All control measures should start in the seed-bed.

Sterilization of Soil.

It is the practice of many growers to steam sterilize the seed-beds in order to destroy disease-producing organisms and also to kill weed seeds. With regard to liability of wildfire infection, our observations have been that it has made little or no difference whether or not the seed-beds have been sterilized. It is, however, a good practice, and will minimize the chances of infection from material containing the organisms which may have remained in the beds. No precautionary measures should be overlooked; therefore, where it can advantageously be done, it is well to change the location of the seed-beds, particularly if sterilization is not practiced.

Seed Disinfection.

Fromme (2) has found that the organism overwinters on the seed, and has devised a method for the sterilization of seed which is apparently satisfactory, and, if carried out exactly according to the recommendations, will not injure the seed. We have sterilized several lots of seed this year, and in none of them has germination been injured. Some bad results have been reported, but these have resulted from faulty technique. Two of the most important points in seed sterilization are thorough washing out of the formaldehyde and rapid drying of the seed. Fromme in principle recommends for sterilization of seed the following procedure: Soak the seed for fifteen minutes in a solution made by adding one fluid ounce of formaldelyde (commercial strength) to a pint of water. Stir the seed all the time that they are in the solution. At the end of the time cover the pail or jar with cheesecloth and wash in running water, or wash in several changes of water until all trace of formaldehyde odor has disappeared. Spread the seed in a thin layer and dry as rapidly as possible at room temperature. Do not heat during the drying.

This treatment will not eliminate the possibility of the occurrence of the disease in the seed-bed, for some of our seed-bed infection this past season occurred after the plants were well developed, but it will eliminate one source of infection, and if the other recommendations are followed will reduce the chances of infection.

Sterilization of Sash, Cloth Covers, etc.

In the South it has been shown that the covers used on the beds are sometimes a source of infection, and it is recommended as an additional precaution that the sash, covers and side plank be washed or sprayed with a solution of formaldehyde, 1 part to 50 by measure, and dried before being used. So far, in Massachusetts, we have no positive proof that the disease is carried over in this way, but possibly it may be.

Spraying or dusting Plants in the Seed-bed.

Although the bacteria when once inside the tissues of the leaf cannot be destroyed by application of any substance to the surface, the possibility of preventing them from entering in the first place is not precluded. Spraying and dusting experiments were therefore undertaken with the object of covering the leaves with a poisonous coat which would kill the bacteria while on the surface and before they had an opportunity to pass through the epidermis.

A cloth-covered seed-bed 40 feet long and 6 feet wide was divided into 18 equal plots, and the fungicides applied for the first time when the plants were about 1 inch high and again a week later. The substances applied, rates of application and results are indicated in the table below. Four of the plots received no applications and were used as checks for comparison. No infection was present at the time of the first application, but on the following day the entire bed was sprinkled equally with a gallon of water suspension of the bacteria. Five days later infection was noted in abundance on the checks. The beds were inoculated again after the second application of the fungicides, although frequent rains in the meantime were causing satisfactory spread. One week after the second application the plants were all pulled, examined one at a time, and data recorded as to number of infections. At that time the plants were of about the right size for setting in the field. The amount of control is probably indicated more nearly by the number of spots than by the percentage of infected plants. A hand-operated 2-gallon compressed air sprayer was used for applying the liquids, and a D and B No. 100 powder blower, manufactured by the Dust Sprayer Manufacturing Company of Kansas City, Mo., was used for dusting.

Tabulation of Spraying Results.

Spray Material.	Plot Number.	Total Number of Plants.	Number of Diseased Plants.	Per Cent of Plants infected.	Average Per Cent of Infection.	Number of Lesions per Plot.
None, ...	5	300	196	66.0	48.25	936
None, ...	2	251	140	55.0		549
None, ...	16	265	96	36.0		223
None, ...	12	263	95	36.0		215
Lime-sulfur, ...	9	298	168	56.0	56.0	562
Sulfur, ...	18	301	19	6.0	6.0	26
Pyrox, ...	6	300	5	1.6	4.1	9
Pyrox, ...	10	270	18	6.7		28
Bordeaux, ...	1	207	2	1.0	1.25	8
Bordeaux, ...	14	266	4	1.5		4
Sanders dust, ...	2	232	2	.8	.55	2
Sanders dust, ...	17	302	1	.3		1
Bordeaux and lead, ...	7	300	0	.0	.5	0
Bordeaux and lead, ...	11	298	3	1.0		8
Pickering, ...	8	300	1	.3	.35	1
Pickering, ...	13	256	1	.4		1
NuRexo, ...	3	300	1	.3	.48	1
NuRexo, ...	15	300	2	.66		2

Notes on Substances used, and Results.

Lime-sulfur. — The ordinary commercial liquid diluted at the rate of 1 part to 40. Very severe burning of the leaves occurred within an hour after application. Since, in addition, no control was secured, it is apparent that lime-sulfur should never be used.

Pyrox. — A commercial Bordeaux paste (arsenical included) prepared by the Bowker Insecticide Company of Boston. Applied at the dilution of 10 pounds to 50 gallons of water. This fungicide was washed from the leaves by the rain to a greater extent than any of the others.

NuRexo. — A Bordeaux preparation (arsenical included) in form of a powder prepared by the Toledo Rex Spray Company of Toledo, Ohio. Diluted at rate of 8 pounds in 50 gallons of water. Adhered to leaves much better than Pyrox, but not so well as freshly prepared Bordeaux. There was a slight trace of burning, but not serious.

Freshly Prepared Bordeaux Mixture. — The ordinary 4–4–50 formula. This was washed away by rain least of all the substances which were tried, and was still to be found on the leaves after repeated heavy rains. No burning occurred.

Bordeaux Mixture and Lead Arsenate. — The Bordeaux as above, but the powdered arsenical added at the rate of 2 pounds to 50 gallons of water. Some of the leaves were burned. There seems little if any benefit to be derived by addition of the lead arsenate.

Pickering's Lime-water Bordeaux. — The clear limewater and copper sulfate solution were mixed in the proportions recommended by Cook in United States Department of Agriculture Bulletin No. 866. Considerable burning was observed, especially after the first application.

Sulfur Dust. — This remained on the leaves very well. This plot did not seem to grow as well as the others and the plants were "off color." Since the percentage of control was not so high as for some of the others, it is not to be recommended.

Sanders Dust. — A very finely ground lime-copper sulfate dust mixture prepared by Riches Piver & Co. of New York. Spreads well, adheres well and causes no burning. Both this and the sulfur dust were applied while the plants were wet with dew or rain.

Spraying Results by Growers.

Three tobacco growers followed our recommendations and sprayed with Bordeaux mixture or commercial substitutes of the same. No careful counts of results were made, but observations showed good control, and confirmed our results on the station plots.

Conclusions as to Spraying and Dusting.

Lime-sulfur and sulfur dust do not give sufficient control; Pickering's mixture and the Bordeaux with the addition of lead arsenate cause burning; Pyrox gave less control than some of the others and washed from the leaves too easily. There seems to be little choice between freshly prepared Bordeaux mixture, NuRexo and Sanders Dust. The percentage of control is about the same with all, and there is very little injury. The dust can be more quickly and easily applied, and the writers believe that it can be made to more nearly cover the lower surfaces of the leaves. They prefer the dust to the liquid. For those who prefer the liquid the home-made Bordeaux has the advantages of cheapness and better adhesion. NuRexo, as well as other commercial Bordeaux pastes and powders, has the advantage of being already prepared.

These conclusions are based on one year's experiments, and therefore should not be accepted as absolute. The experiments will be repeated for several years before final conclusions are drawn.

Aeration and Watering of Beds.

As a result of observations and experiments conducted during the season, it is recommended that the watering of the beds be done as seldom as possible, as the splashing of the water drops from plant to plant was found to spread the disease rapidly. Most of the beds are watered too much and

the humidity is often very high under the sash. Water of condensation dripping from the sash to the plants also appears to be responsible for some spread. The beds should be run as dry and with as much air circulation as possible. This tends to dry off the leaves, and helps reduce the spread of the disease. In many instances where this was practiced after infections were found, spread was much slower than when the beds were closed tightly and very little if any air circulation permitted. Careful attention to this matter will result also in stronger, better plants.

Fertilizer Relations.

While fertilizer materials are not directly responsible for the disease, there is apparently a relation between the rapidity of spread in the seed-bed and the application of excessive amounts of some materials. This was particularly noted in the case of nitrogen. Where excessive amounts of nitrogen were applied to infested beds, the disease was much more serious on the parts so treated than on those sections to which no additional nitrogen was applied. It was also noted that where growers applied potash to infested beds the spread of the trouble was less than on sections of the beds where none was applied. There have been no careful experiments on the relation of fertilization to susceptibility, but it is known that excessive nitrogen applications force rapid succulent plant growth, with little resistance to any change in environment or disease invasion. Potash is said to cause strengthening of the green parts of the plant, and make it stockier and less susceptible to disease and change in environment. This question cannot be considered settled, and experiments are under way to check up on this point as related specifically to wildfire.

Selecting Plants from Disease-free Beds.

Plants from infested seed-beds should never be set in the field, even though the infection is slight. During the past season it was observed that although plants in and around the infected areas were killed out with formaldehyde, some infection, undeveloped at the time, appeared later, and subsequently many of these beds became heavily infected. Many of the lesions are so small and inconspicuous that they escape any but the most careful observation. A single observation of the seed-bed in the early part of the season is not an indication that the beds will remain free from disease. This was shown by the fact that there were two and possibly three recurring epidemics this past spring, the last occurring almost at the end of the setting season. It was the experience of many growers that while the early set plants from their beds showed none of the disease in the field, the late set plants developed the disease, and it was also noted that many of the plants used for restocking showed the trouble even when pulled from the same beds from which the field was set, and that the disease occurred only on these plants.

Relative Susceptibility of Varieties.

In the seed-bed the different varieties of tobacco seem to show no difference in susceptibility to the disease, but under field conditions the spread of the disease seems to be governed somewhat by the manner and type of growth of the variety. Shade Cuban seems to be but little affected with the trouble after setting in the field. Here the protection afforded by the tent undoubtedly has something to do with it, as the rain and wind is broken; also the open habit of growth, with the leaves relatively far apart, minimizes the chances for a rapid spread. The same is true of the Havana to a less extent, the leaves of this variety, also, having an upright habit of growth, and touching but little.

The practice of priming the leaves of the Shade Cuban and some of the Havana is also an important factor in reducing the spread of the disease, as the first priming is made early, and this includes usually the infected leaves. In this way, as will be noted under the subject of removal of diseased leaves, a large amount of field infection probably is prevented. Perhaps Broadleaf suffers most of all the varieties, as, when the leaves get their growth, they droop and touch each other and also leaves of near-by plants, and thus infection occurs more easily.

During this past season a great deal of late infection in the field has been observed, *i.e.*, many fields of Broadleaf showed practically no infection prior to topping, but after a few days, as the plants were maturing, showed a rapid spread of the disease. Cases have been called to the attention of the writers where the typical halo spots were found on all leaves of the plant. During this past season there was a large amount of "rust" on Broadleaf in some sections, and this has been confused by growers and others with true wildfire. The writers wish to point out the possibility that part of this spotting was caused by excess of nitrogen and deficiency of potash, not sufficient in the case of the latter to show symptoms of potash hunger, but enough to cause a rusting. This rusting occurs on some of the tobacco in Carolina, and has been demonstrated to be a result of the above-mentioned conditions; and this *may* be true of some of the spotting of Broadleaf, and possibly the other varieties, since very little potash has been used during the past four or five years. There is, however, no experimental evidence to warrant this statement as a fact so far as our Massachusetts conditions are concerned.

Removal of Diseased Plants or Leaves from the Field.

When the disease has become established in the field, spraying operations are not practicable. The only promising method of control at this stage seems to be the elimination of diseased plants or leaves. If infection in a field is found to be pretty general early in the season, it is perhaps best to remove all the plants and replant from a bed known to be free from the disease, if such can be found. In two fields containing thirty-

five acres of tobacco, entire removal and replanting in this way was practiced with complete success. Practically no infection was found in either field at the close of the season. If the infection is light and the season is not far advanced, only the affected plants should be removed and destroyed, and healthy ones from disease-free beds substituted. When a light infection occurs late in the season there is a fair chance of keeping it under control by careful removal of the diseased leaves only. Good control was secured in this manner in a number of fields which came under the writers' observation during the past season.

Working only with Dry Plants.

In the previous pages the connection of water with dissemination and infection has been explained. If wildfire is known to be present and one wishes to keep it under control, obviously all operations should cease when the leaves are wet from dew or rain.

CONDENSED RECOMMENDATIONS FOR CONTROL.

1. Save seed only from disease-free plants.
2. Sterilize seed.
3. Sterilize seed-beds with steam or formaldehyde, or, when the disease has been in beds the previous year, change the location if practicable.
4. Spray or wash sash, plank or cloth with formaldehyde.
5. Spray or dust the beds with a fungicide weekly from the time the plants are the size of the thumb nail until setting is completed.
6. Water beds only sufficiently to keep plants growing. Ventilate thoroughly.
7. Set plants from disease-free beds only.
8. If badly diseased plants are found in the field, remove and destroy them.
9. If infection in the field is light or occurs late in the season, pick and destroy the diseased leaves when they are not wet from dew or rain.
10. As far as possible avoid working in the tobacco when the leaves are wet.

LITERATURE CITED.

(1) Chapman, G. H. Tobacco Wildfire. M. A. C. Ext. Cir. 82. 1920.
(2) Fromme, F. C. Wildfire and Angular Spot. In Va. Agr. Exp. Sta. Ext. Bul. 62: 25–30. 1920.
(3) Wolf, F. A. Tobacco Wildfire. N. C. Ext. Cir. 61. March, 1918.
(4) Wolf, F. A., and Foster, A. C. Bacterial Leaf Spot of Tobacco. Science 46: 361–362. 1917.
(5) Wolf, F. A., and Foster, A. C. Tobacco Wildfire. Journ. Agr. Res. 12: 449–458. 1918.
(6) Wolf, F. A., and Moss, E. G. Diseases of Flue cured Tobacco. N. C. Dept. Agr. Bul. 263.

BULLETIN No. 204.

DEPARTMENT OF CHEMISTRY.

THIRTY YEARS' EXPERIENCE WITH SULFATE OF AMMONIA.

BY F. W. MORSE.

Sulfate of ammonia has been used for many years at the Massachusetts Agricultural Experiment Station in field experiments with fertilizers. Sometimes the effects have been excellent and at other times positive injury to crops has apparently been caused by its use. The object of this bulletin is to show the conditions under which sulfate of ammonia has been used, and to point out the way that seems likely to give favorable results when it is applied as a fertilizer. No attempt is made to show its effect in comparison with the other nitrogenous fertilizers used on adjacent plots in the same field. The comparative results have been reported from year to year in the publications of the Experiment Station, and nitrate of soda has been superior to the sulfate of ammonia in crop production per unit of nitrogen.

In determining the significance of the data herein presented, the following suggestions may be of value: —

1. Sulfate of ammonia as a source of nitrogen was used year after year in a single arbitrary quantity. It is fair to assume that had the application been varied in amount, as indicated by the probable need of nitrogen of the crop to be grown, better average results would have been secured. Present averages include years in which sulfate of ammonia could not have been expected to bring marked response.

2. It is possible, and in fact probable, that to depend on a single source of nitrogen is unsound fertilizer practice. What would have happened had the sulfate of ammonia been combined with other sources of nitrogen is of course a question.

3. The amount of fertilizer nitrogen applied as sulfate of ammonia was in no way dictated by the value of the crop to be grown. This being the case, any computation as to the profits derived from the use of this material is absolutely meaningless. It was not applied on any profit-making basis.

History of Plots.

The plots on which the sulfate of ammonia has been employed were laid out in 1883 as a part of the first experiment field prepared by the late C. A. Goessmann after the founding of the State Agricultural Experiment Station in 1883. During the first six years the field was used as a soil test, and corn was grown every year. In 1889 the plans were rearranged to permit a comparison of standard nitrogenous fertilizers, which has continued to the present time. The experiments have been described with more or less detail in the annual reports of the Experiment Station, under the headings Field A, and Experiments with Nitrogenous Fertilizers. The earlier reports were prepared by the late Director Goessmann,[1] and the later ones by Director W. P. Brooks.[2]

Soil Conditions.

The surface of the field has a slight, uniform slope toward the east and south. The soil and subsoil are a sandy loam classified in the soil survey of the Connecticut Valley as Norfolk, but later reclassified as Merrimac.[3] At a depth of 4 to 5 feet, as shown by the excavation for drains, the field is underlain by the boulder clay of glacial till. The geological formation is that of a river delta,[4] and excavations for buildings in the vicinity of the plots have shown no stratification in the underlying earth, but irregular masses of coarse and fine material so hard and compact as to require constant use of the pick in excavating. Although the surface soil is quite uniform, there is considerable variation in the depth to the till, which possibly causes some of the differences between plots handled uniformly alike.

Fertilizer and Lime Treatment.

The field is laid out in 11 plots of one-tenth acre each, separated from one another by strips 5 feet in width. A drain of 2-inch tile runs lengthwise through the center of each plot at a depth of 3 feet, and empties into a well formed of 24-inch tile, 4 feet deep, at the bottom of which runs the main drain along the eastern border of the field.

The plots compared in this report are numbered 4, 5, 6, 7, 8 and 9. Sulfate of ammonia has been applied to 5, 6 and 8 at the rate of 225 pounds per acre, while 4, 7 and 9 have received no nitrogen since 1882, and probably a number of years preceding that.

During the preliminary soil test, 1883–88, plots 6 and 8 were unfertilized, while 5 received sulfate of ammonia. Since 1889 all the plots have received per acre 80 pounds of available phosphoric acid in superphosphates, and 125 pounds of potash in potash salts. Plots 4 and 5 have

[1] Mass. Agr. Expt. Sta., Ann. Repts., 1883 to 1896, inclusive.

[2] Mass. Agr. Expt. Sta., Ann. Repts., 1897 to 1917, inclusive.

[3] Soils of the United States. Bul. No. 55, Bureau of Soils, U. S. Dept. Agr., p. 158.

[4] B. K. Emerson. Geology of Old Hampshire County.

received low-grade sulfate of potash-magnesia, while 6, 7, 8 and 9 have had muriate of potash applied to them.

The plots have had applications of lime at irregular intervals. In 1894, plot 8 alone received a small application of air-slaked lime at the rate of 500 pounds per acre, because it had been persistently inferior to all others in production. The lime produced a favorable effect. All the plots were dressed with hydrated lime in 1898 and again in 1905, at the rate of 1 ton per acre each time. The east half of each plot received an application of hydrated lime in 1909 at the rate of 5,000 pounds per acre, and again in 1913 at the rate of 4,000 pounds per acre.

The east half of the field is positively moister than the west half, so that a fair comparison between the yields produced with lime and those without it cannot be made; but the effects of liming on the relations of the plots to each other can be determined.

The arrangement of the plots permits the comparison of yields from the plots treated with sulfate of ammonia with the yields from plots without nitrogen lying directly beside them.

Scheme of Fertilization of Plots.

North.

9.	No nitrogen, superphosphate, muriate of potash.		
	Lime.	1898, 1905.	1898, 1905, 1909, 1913.
8.	Sulfate of ammonia, superphosphate, muriate of potash.		
	Lime.	1894, 1898, 1905.	1894, 1898, 1905, 1909, 1913.
7.	No nitrogen, superphosphate, muriate of potash.		
	Lime.	1898, 1905.	1898, 1905, 1909, 1913.
6.	Sulfate of ammonia, superphosphate, muriate of potash.		
	Lime.	1898, 1905.	1898, 1905, 1909, 1913.
5.	Sulfate of ammonia, superphosphate, sulfate of potash-magnesia.		
	Lime.	1898, 1905.	1898, 1905, 1909, 1913.
4.	No nitrogen, superphosphate, sulfate of potash-magnesia.		
	Lime.	1898, 1905.	1898, 1905, 1909, 1913.

South.

Yields on No-nitrogen Plots.

The yields of the plots without nitrogen, 4, 7 and 9, have been closely studied to ascertain whether there were any consistent differences in their production which might be due to variations in soil; but no uniform relations have been found. During the thirty years, 1889–1918, there was but one season, 1892, when the yields of the three were closely alike. Sometimes one plot has been the best and at other times the poorest. Plot 7 has been the highest in twelve years and the lowest in seven, while plot 4 was highest in eleven and lowest in fifteen years; therefore 7 may be a little the best, while 4 has been possibly a bit poorer than 9. But the differences are slight and cannot be used to explain the variations in yields on the plots receiving sulfate of ammonia. Previous to 1910 the divergences between the highest and the lowest yields on these plots without nitrogen were often from 25 to 30 per cent, and even more, while after the somewhat heavy liming in 1909 — though it covered only one-half the area — the divergences were nearly always less than 10 per cent.

Yields on Sulfate of Ammonia Plots.

The yields on the plots which receive sulfate of ammonia have been somewhat erratic, with first one plot and then the other showing marked inferiority to the other two, and also to the adjacent plots which receive no nitrogen. There is an indication from the flow of drainage water that plot 8 may have soil slightly more open in texture than the soil of 5 and 6; otherwise there is no apparent reason for the variations that have occurred in the yields of these plots in different seasons, by which 8 has oftenest been the lowest producer.

Tables of rainfall and crop yields are given on pages 88 and 89. The gross weights of crops for the individual plots are used without division into grain and straw when the cereals are listed. Nitrogen is definitely known to be a promoter of plant growth rather than maturity, hence the total weight per plot is a proper measure of the crop-producing power of a nitrogenous fertilizer.

Crops Grown.

Eight different kinds of crops have been grown in the period of thirty years covered by the tables. Each kind of crop is taken up separately in discussing the comparative yields from the plots with sulfate of ammonia and from those without it.

Corn. — Corn has been grown in five of the seasons included in this summary. The first crop was in the first year of the experiment. Corn had been grown continuously since 1883, and soil conditions had become such that the yield was smaller than in any of the subsequent years; therefore this year will not be considered in the discussion. The four crops to be compared were grown under somewhat varied conditions of soil and previous cropping.

The crop of 1906 followed the 1905 crop of oats and peas when the land was limed. The sulfate of ammonia plots produced about 20 per cent more weight than the plots without nitrogen. In 1911 the corn followed four successive years of hay production, including some clover, and an application of lime over the east half of the plots in the fall of 1909. The yields without nitrogen exceeded those with ammonia by a small amount, between 2 and 3 per cent. Corn was raised again the next year, and the results were changed, the ammonia plots producing about 7 per cent more weight. The spring months of 1911 were dry, also June and July of 1912. In 1918 corn was the last crop of this period. It had been preceded by potatoes in 1917, millet in 1916 and clover in 1915, previous to which (in 1913) the east half of the plots had been heavily limed. The crop from the limed and unlimed areas was harvested separately. In the presence of lime, the ammonia plots produced an increase of 28 per cent over the no-nitrogen plots, while without lime they were slightly inferior to the plots without nitrogen.

TABLE III. — *Average Yield of Corn (Ears and Stover) (Pounds per Acre).*

	1889.	1906.[1]	1911.[2]	1912.	1918.[3]	
					Unlimed	Limed.
No nitrogen,	4,600	8,940	10,150	9,980	8,680	11,380
Sulfate of ammonia,	4,630	10,690	9,880	10,720	8,420	14,640
Percentage increase,	–	19	–	7	–	28

[1] After oats and peas with lime.
[2] After clover with lime applied to half area.
[3] Last limed in 1913 over half area.

Oats. — Seven crops of oats were grown during the years covered by the experiment. The first crop (1890) followed the continuous corn culture practiced for seven years. The next three crops (1893, 1895, 1897) alternated with crops of soy beans. In 1898 the crop followed the oats of 1897, but the land was limed before seeding at the rate of 2,000 pounds per acre of air-slaked lime, and the oats were sown as a nurse crop for clover. In 1905 oats were combined with field peas and followed a crop of potatoes, and the land was again limed at the rate of 2,000 pounds of air-slaked lime per acre. Up to this point the land had been plowed every year since 1883, except 1899. In 1914 oats were sown as a nurse crop for clover, after three years of tilled crops, — two of corn and one of Japanese millet. The east half of the plots had been limed in 1909 and 1913. The last two crops of oats were cut for hay and the others were permitted to ripen the grain. The rainfall in 1890, 1893 and 1895 had been well distributed during the months of growth, and was about normal in amount.

TABLE I. — *Rainfall in Inches.*

YEAR.	April.	May.	June.	July.	August.	September.	Total for Year.
1889,	2.87	4.71	5.01	7.55	**2.35**	**2.36**	40.37
1890,	**1.35**	4.56	**1.42**	5.23	4.06	4.86	**39.48**
1891,	**1.55**	**1.64**	4.36	4.93	3.13	**1.78**	**34.82**
1892,	**.54**	4.73	2.61	3.28	5.23	**1.29**	40.35
1893,	**2.20**	3.17	**2.42**	**1.77**	**2.10**	**1.88**	46.94
1894,	9.85	2.92	**1.69**	**.99**	**.19**	**2.38**	**32.64**
1895,	5.56	**2.07**	2.76	3.87	3.46	5.04	44.46
1896,	**1.32**	2.58	2.57	4.96	3.84	5.41	**39.66**
1897,	**2.42**	4.38	6.65	14.51[1]	4.29	**1.94**	57.05
1898,	3.73	5.61	3.69	4.09	6.85	3.65	53.89
1899,	**1.79**	**1.28**	4.13	4.89	**2.00**	7.90	41.49
1900,	**1.85**	3.78	3.65	4.67	4.11	3.67	51.67
1901,	5.95	6.91	**.87**	3.86	6.14	4.17	49.72
1902,	3.31	**2.32**	4.54	4.66	4.65	5.83	46.99
1903,	**2.30**	**.48**	7.79	4.64	4.92	**1.66**	45.45
1904,	5.73	4.55	5.35	2.62	4.09	5.45	45.30
1905,	2.56	**1.28**	2.86	2.63	6.47	6.26	**38.80**
1906,	3.25	4.95	2.82	3.45	6.42	2.59	45.15
1907,	**1.98**	4.02	**2.36**	2.87	**1.44**	8.74	42.27
1908,	**1.97**	4.35	**.76**	3.28	4.27	**1.73**	**30.68**
1909,	5.53	3.36	**2.24**	**2.24**	3.79	4.99	**39.12**
1910,	3.07	2.67	2.65	**1.90**	4.03	2.86	**36.11**
1911,	**1.87**	**1.37**	**2.02**	4.21	5.92	3.41	44.21
1912,	3.92	4.34	**.77**	2.61	3.22	2.52	**38.56**
1913,	3.30	4.94	**.90**	**1.59**	**2.26**	2.56	**39.50**
1914,	6.59	3.56	**2.32**	3.53	5.11	**.52**	41.83
1915,	3.99	**1.20**	3.00	9.13	8.28	**1.37**	51.58
1916,	3.69	3.21	5.34	6.85	**2.49**	5.08	45.61
1917,	**1.83**	4.13	5.27	3.36	7.06	**2.42**	43.56
1918,	2.78	**2.47**	4.01	**1.84**	**2.22**	7.00	**37.47**

[1] Eight inches the 13th and 14th.

Black-face type shows a rainfall much less than normal. It may be noted that from 1907 to 1913 there was a period of deficient rainfall, and the soil grew drier and drier each succeeding year. A short period of spring or summer drought during these years was responsible for pronounced ill effects from the sulfate of ammonia, although the liming of one-half the area conceals the injury in the averages. The period following, as a whole, had a high rainfall, and toxic effects from the ammonia salt were not noticeable on the unlimed area. In 1918 another period of low rainfall occurred, running over into the spring of 1919, when corn was particularly affected by the sulfate of ammonia on the unlimed sections of plots 5 and 6, as described in detail toward the end of this bulletin.

Table II. — *Crop Yields (Pounds per Plot).*

Year.	Crop.	Plot 4. No Nitrogen.	Plot 5. Sulfate of Ammonia.	Plot 6. Sulfate of Ammonia.	Plot 7. No Nitrogen.	Plot 8. Sulfate of Ammonia.	Plot 9. No Nitrogen.
1889	Corn (ears and stover), .	381	438	541	525	359[1]	475
1890	Oats (grain and straw), .	260	360	385	329	220[1]	290
1891[2]	Rye (grain and straw), .	390	530	400	150	-	425
1892	Soy beans, green, .	1,140	1,935	1,970	1,430	1,450[1]	1,460
1893	Oats (grain and straw), .	590	630	600	550	420[1]	480
1894	Soy beans, green, . .	405	645	615	480	680	470
1895	Oats (grain and straw), . .	343	550	560	428	450	430
1896	Soy beans, green, . .	1,130	1,582	1,870	1,240	1,980	1,050
1897	Oats (grain and straw), . .	189	477	372	197	477	205
1898[4]	Oats (grain and straw), .	136	238	269	167	278	171
1899	Clover hay, ...	325	340	340	342	420	390
1900	Potatoes, ...	1,387	1,343	1,247	1,268	1,215	1,108
1901	Soy beans (seed and straw), .	428	393[1]	485	385	423	382
1902	Potatoes, . .	1,011	1,002	1,218	1,114	978	1,013
1903	Soy beans (seed and straw), .	269	246	183	177	225	125
1904	Potatoes, ...	758	1,059	691	694	876	1,066
1905[4]	Oats and peas (hay), .	435	565	660	480	690	390
1906	Corn (ears and stover), . .	957	1,048	1,044	850	1,115	875
1907	Clover hay, ...	310	295	222[1]	300	260	260
1908	Clover hay, ...	340	358	215[1]	463	505	465
1909[3]	Clover hay, ...	395	437	420	315	450	375
1910	Hay, ...	640	722	700	675	680[1]	705
1911	Corn (ears and stover), . .	1,047	996[1]	1,010	956	958[1]	1,042
1912	Corn (ears and stover), . .	950	1,056	1,043	1,034	1,118	1,010
1913[5]	Japanese millet (hay), . .	730	1,020	1,120	670	1,220	670
1914	Oats (hay), ...	190	230	290	205	335	200
1915	Clover hay, ...	845	770[1]	835	783	820	800
1916	Japanese millet (seed and straw),	585	580[1]	675	645	675	640
1917	Potatoes, ...	1,890	1,664	1,669	1,459	1,644	1,463
1918	Corn (ears and stover), . .	936	1,045	1,123	1,055	1,291	1,018

1 Sulfate of ammonia was apparently injurious.

2 Crop on plot 8 destroyed by insects.

3 Plot 8 received an application of lime.

4 All plots limed on their entire area.

5 The east half of every plot was limed.

Of the plots receiving ammonia, No. 8 made the poorest yield year after year without regard to kind of crop. In 1897 and 1898 the seasons were excessively wet, and plot 8 equaled or exceeded the other plots. It has been mentioned that this plot has appeared to be a little drier than the remainder of the field, which accords with its variable yields in the different seasons.

The sulfate of ammonia was beneficial in each year, but in 1893, a year of well-distributed average rainfall, the plots without nitrogen yielded their maximum crop and nearly equaled the yields of the ammonia plots. In 1897 and 1898 the ammonia produced marked increases in yields under adverse conditions of heavy rainfall and wet soil.

TABLE IV. — *Average Yield of Oats (Grain and Straw) (Pounds per Acre).*

	1890.	1893.	1895.	1897.	1898. [1]	1905. [1]	1914. [1]	
							Unlimed.	Limed.
No nitrogen,	2,900	5,400	4,600	1,970	1,580	4,350 [2]	1,420 [2]	2,530 [2]
Sulfate of ammonia,	3,220	5,700	5,200	4,420	2,620	6,380 [2]	2,160 [2]	3,530 [2]
Percentage increase,	11	2	30	124	65	46	52	39

[1] Limed in 1898 and 1905 over whole area, and in 1909 and 1913 over half area.
[2] Harvested as hay.

Soy Beans. — Five crops of soy beans were grown in this experiment. Three of them (1892, 1894 and 1896) alternated with grain crops and were cut and weighed green. The season of 1894 was extremely dry, with but 9 inches of rain from April 1 to October 1; consequently the yield in this season was much less than in the other two, when the rainfall was about normal. Plot 8 was given a light dressing of lime in 1894, which resulted in maximum yields on this plot in both 1894 and 1896.

The other two crops were grown in 1901 and 1903 and followed potatoes in each case. In 1898 the field had been limed over its entire area. The two crops ripened their seed, and the weights of the combined straw and beans are given. The rainfall was abundant as a whole, but June, 1901, and May, 1903, were each dry months, and may have influenced the yields somewhat.

In the earlier period sulfate of ammonia produced a marked effect on the crops, reaching a maximum of nearly 60 per cent increase in 1896. The crops of the second period were benefited but little by the ammonia. Probably by this time the soil had become naturally inoculated with the soy bean bacteria for fixing nitrogen from the air, for the soy beans grew nearly as well on the plots without nitrogen as on those which received sulfate of ammonia. In 1901 it was recorded that nodules were abundant on the roots.

PLATE I.—CHARACTER OF VEGETATION ON UNLIMED PLOTS, 1920.

Photo. by R. L. Coffin.

With sulfate of ammonia. Yield per acre, 2,620 pounds.

Photo. by R. L. Coffin.

With nitrate of soda. Yield per acre, 4,180 pounds.

Photo. by R. L. Coffin.

With sulfate of ammonia. Yield per acre, 6,095 pounds.

Photo. by R. L. Coffin.

With nitrate of soda. Yield per acre, 6,130 pounds.

TABLE V. — *Average Yield of Soy Beans (Pounds per Acre).*

	1892.[1]	1894.[1]	1896.[1]	1901.[2]	1903.[2]
No nitrogen,	14,430	1,520	11,430	3,980	1,900
Sulfate of ammonia,	17,850	6,470	18,110	4,340	2,180
Percentage increase,	23	43	58	9	14

[1] Weight in green state. [2] Weight dry and ripe.

Potatoes. — Potatoes have been grown four times, three of them in alternate years, 1900, 1902 and 1904, in which period the first crop followed clover and the other two followed soy beans. The soil had been limed in 1898. The seasons were all normal in rainfall. In these three years it is noticeable that the crop steadily diminished year by year on all plots, and in no year was there any appreciable benefit from the sulfate of ammonia; neither can it be said to have injured the crop, as the soil gradually lost the effects of the lime of 1898. It must be considered that either clover or lime had a more positively favorable result than soy beans or sulfate of ammonia.

In 1917 potatoes followed millet, which in turn was preceded by clover in 1915. The east half of each plot had been heavily limed in 1913. On the limed areas there was no advantage from the sulfate of ammonia. On the unlimed areas there was a small gain from its use. The unlimed areas had received no lime since 1905, while the limed had been dressed in 1909 as well as in 1913. Under the conditions of this experiment, which are in no case abnormal, sulfate of ammonia was of little benefit to potatoes.

TABLE VI. — *Average Yield of Potatoes (Pounds per Acre).*

	1900.[1]	1902.[2]	1904.[2]	1917.[3]	
				Unlimed.	Limed.
No nitrogen,	12,540	10,690	8,390	12,060	20,020
Sulfate of ammonia,	12,680	10,660	8,760	12,900	19,340
Percentage increase,	1	–	4	7	–

[1] After clover. [2] After soy beans. [3] Lime last applied in 1913 over half area.

Grass and Clover. — A hay crop consisting largely of clover has been grown in six of the years, but not in any systematic rotation.

The first crop was red clover in 1899. It had been sown the previous year with oats as a nurse crop, and the land received a dressing of lime over the whole area. The clover was winterkilled somewhat, and was unevenly distributed. There was a small gain on the plots receiving the sulfate of ammonia.

The crop of 1915 was produced under similar conditions. The plots were seeded in the spring of 1914 with oats as a nurse crop. The soil had been heavily limed in 1913 on the east half of the plots, but the west half had received none since 1905. The clover was sown in a mixture with redtop and timothy. After the oats were cut the rainfall was sufficient to start the clover promptly, and it grew faster than the timothy and redtop except on the unlimed parts of the sulfate of ammonia plots, where redtop became the principal crop. No cutting was made that season, and the clover and redtop wintered in perfect condition. The two halves of each plot were harvested and weighed separately. On the unlimed half the clover without nitrogen outyielded the redtop with sulfate of ammonia, but on the limed half the sulfate of ammonia produced about 10 per cent more clover than was produced without it. The rainfall was well distributed during the growing periods of 1899 and 1915.

Four of the clover crops, consisting of alsike clover, were grown in four successive years (1907, 1908, 1909 and 1910) as annual crops. The first crop was sown in the corn in the summer of 1906. It did not winter satisfactorily, and after the hay had been removed in 1907 the land was plowed and reseeded with clover. Conditions repeated themselves in 1908 and again in 1909. In no season was there a good stand of alsike clover, but the vacant spaces filled up with weeds or volunteer grasses. The rainfall in 1906 and 1907 was normal; in 1908, 1909 and 1910 it was continuously below normal, but in general was well distributed, and the soil grew steadily drier. The crop of 1909 was from one-fourth to one-half weeds by actual weights. It was the only year of the four in which the plots receiving sulfate of ammonia considerably exceeded in yield those without nitrogen. In the fall of 1909 the east half of the plots was top-dressed with hydrated lime, and in 1910 the crop consisted of much more timothy than clover, with a slight gain on the ammonia.

TABLE VII. — *Average Yield of Hay (Pounds per Acre).*

	1899.[1]	1907.[1]	1908.[1]	1909.[1]	1910.[2]	1915.[2] Unlimed.	1915.[2] Limed.
No nitrogen,	3,520	3,000	4,230	3,620	6,730	8,130	8,050
Sulfate of ammonia,	3,670	2,590	3,590	4,360	7,010	7,300	8,870
Percentage increase,	4	-	-	20	4	-	10

[1] Lime applied in 1898 and 1905 over whole area.
[2] Lime applied in the fall of 1909 and in 1913 over half area.

Japanese Barnyard Millet. — This has been grown twice and the two crops have been produced under quite different conditions. The first crop was grown in 1913 and followed two successive corn crops. The soil had been limed on the east half of the plots in 1909 and 1913. The

millet was cut for hay when the seed had formed but had not filled out. The crop of 1916 was a catch crop. The land had produced an excellent crop of clover the preceding year, and the stubble had been plowed under. Potatoes were planted early in the spring of 1916, but the stand proved too uneven to be satisfactory for the experiment, and the land was plowed and seeded to millet in the early summer. The crop was ripened and cut for seed.

In 1913 continuous tillage with corn for two years had used most of the organic nitrogen in the soil, and the sulfate of ammonia plots yielded 60 per cent more than those without nitrogen. In 1916, when there was a lot of organic nitrogen from the clover stubble, the no-nitrogen plots produced almost as well as those with ammonia.

TABLE VIII. — *Average Yield of Japanese Millet (Pounds per Acre).*

	1913.[1]	1916.[2]
No nitrogen,	6,900	6,230
Sulfate of ammonia,	11,200	6,430
Percentage increase,	62	3

[1] Limed over half area. Crop harvested as hay.
[2] After clover, Crop ripened for seed.

SUMMARY OF RESULTS BY CROPS.

Corn was benefited by the sulfate of ammonia in 1906, 1912 and 1918 where lime was present and the land had not recently been in sod. In 1911, following four years of grass and clover, the ammonia was ineffective. Without lime, on old ground, in 1889 and 1918, ammonia was ineffective.

Oats responded to sulfate of ammonia every year in which they were grown. The crop was least responsive in 1893, which was a season of favorable rainfall, and the plots without nitrogen gave a maximum yield.

Soy beans were benefited by the sulfate of ammonia, but its effectiveness grew less as natural inoculation of the soil developed.

Potatoes received little benefit from the ammonia under the conditions of the experiment.

Clover was discouraged by sulfate of ammonia in the absence of lime. Redtop was benefited by the ammonia without lime. Grasses in general require lime with the sulfate of ammonia.

Japanese millet was much increased by the sulfate of ammonia on old ground; but following clover the ammonia had but little effect.

HISTORY OF THE PLOTS IN 1919 AND 1920.

Corn and hay have been produced in the two years succeeding the period that has been included in the tables and summary. In 1919 the plots received an application of ground limestone at the rate of 2,000 pounds per acre. The lime was applied on the north half of each plot, lengthwise of the area, instead of on the east half crosswise of the plots, as heretofore. Plot 6 received no lime at this time, while its duplicate, plot 8, was limed throughout. This rearrangement, it is believed, will lead, as time passes, to a fairer comparison between the results obtained with lime and those without lime.

In the preparation of the preceding tables it was deemed best not to include the crop of 1919, while that of 1920 had not yet been produced. Now it seems proper to place them by themselves and amplify the results already shown.

The crop in 1919 was corn, which was grown as a preliminary step to seeding with grass in the summer. Hay from mixed timothy, redtop and clover was produced in 1920. The rainfall for the two years and the crop yields are tabulated below.

TABLE IX. — *Crop Yields of 1919 and 1920 (Pounds per Acre).*

	1919.		1920.	
	CORN (EARS AND STOVER).		HAY FROM MIXED GRASSES.	
	Unlimed.	Limed.	Unlimed.	Limed.
No nitrogen,	7,520	8,060	2,760	3,540
Sulfate of ammonia,	8,480	10,120	4,620	6,480
Percentage increase,	12	25	67	83

TABLE X. — *Rainfall, Seasons of 1919 and 1920.*

	April.	May.	June.	July.	August.	September.	Total for Year.
1919,	2.37	6.20	1.09	4.17	4.81	4.25	41.42
1920,	4.71	3.65	6.26	2.06	3.62	6.74	50.09

The value of lime in conjunction with sulfate of ammonia is well shown in these two crops. Although the ammonia produced an increase without lime, the gain with lime was much greater. The absence of clover from the unlimed areas in 1920 was striking, and redtop was the main crop instead. On unlimed areas, with both corn and grass, sulfate of ammonia showed injurious effects which are discussed later.

Peculiar Effects of Sulfate of Ammonia.

A comparison of the crop yields from the plots receiving sulfate of ammonia with those from the plots without nitrogen reveals some striking extremes in the effects of the ammonia compound on plant growth. The largest percentage of gain produced by the sulfate of ammonia was on oats in the years 1897 and 1898, when rainfall was unusually high and the actual yields were among the lowest of the entire period. There are frequent instances, on the other hand, when the crops on the plots without nitrogen were better than those with sulfate of ammonia, which in some cases appeared to have been positively injurious. These ill effects were irregular, and seldom occurred on all three ammonia plots in one season. A study of the rainfall has shown that these apparently injurious effects occurred in seasons when there was a drought in May or June. Applications of lime have remedied the injurious action, but at the same time have tended to bring up the yields on the plots without nitrogen, so that the percentages of increase due to the ammonia are seldom large.

Examination of the soils from the different plots of Field A has shown that, in the absence of lime, the sulfate of ammonia forms soluble sulfates of manganese, aluminium and iron, sometimes one, sometimes another, and again all three.[1] Any one of these substances, if present in comparatively small amount, has been shown to be poisonous to plants, especially to clover.

The rearrangement of the limed areas in 1919 resulted in four distinct gradations of limed soil, as follows: —

Last limed in 1905,	Plots 4, 5, 7, 9, Southwest quarter. Plot 6, West half.
Last limed in 1913,	Plots 4, 5, 7, 9, Southeast quarter. Plot 6, East half.
Limed in 1905 and 1919,	Plots 4, 5, 7, 9, Northwest quarter. Plot 8, West half.
Limed in 1913 and 1919,	Plots 4, 5, 7, 9, Northeast quarter. Plot 8, East half.

In 1919 there was a very striking injury to corn on the long unlimed parts of plots 5 and 6. Injury was not apparent on plot 8, as the entire plot had been limed that spring. The plants were stunted in size; the lower leaves were light colored, reddish and yellowish in streaks, and ultimately turned brown and became dry and brittle. Samples of these leaves were dried and incinerated, and the ash gave a bright greenish blue reaction when fused with sodium carbonate, showing that manganese was present in noticeable amount. This was undoubtedly the cause of the injury.

The field was seeded with a mixture of timothy, redtop and clover in the late summer. The areas long unlimed on plots 5 and 6 were bare of

[1] Ruprecht and Morse. Mass. Agr. Expt. Sta. Bulls. Nos. 161, 165, 176.

vegetation, as the seed either did not germinate or the plantlets soon died. In the spring of 1920 these barren areas were twice reseeded, and finally the redtop grew and developed normally.

In July and in October, 1920, samples of soil were taken from the different sections of plots 5 and 6, the soluble manganese extracted by water, and its weight carefully determined by Mr. C. P. Jones.

TABLE XI. — *Manganese Sulfate in the Surface Soil of Plots 5 and 6.*

[Weight of one acre of soil 6 inches deep assumed to be 1,500,000 pounds.]

Plot.	Lime Treatment.	Manganese Sulfate (Pounds per Acre).
5, Southwest quarter,	Limed, 1905,	235
5, Southeast quarter,	Limed, 1913,	17
5, Northwest quarter,	Limed, 1905 and 1919,	107
5, Northeast quarter,	Limed, 1913 and 1919,	24
6, West half,	Limed, 1905,	177
6, East half,	Limed, 1913,	19

The application of 225 pounds of sulfate of ammonia is theoretically capable of forming 257 pounds of manganese sulfate. There were found small quantities of aluminium sulfate, but only a trace of iron in the soils that were longest without lime.

The weight of evidence indicates that the injurious results were due to the quantity of manganese sulfate present. The actual concentration of the manganese in the soil solution is mere guesswork, but it is interesting to note that its striking injury occurs in seasons of droughts or following a dry period, while plenty of rainfall appears to remove the poison or to dilute it to a harmless concentration.

The effect of lime in preventing the formation of the manganese sulfate is shown by the marked reduction in the amount found where lime had been used as long ago as 1913. The actual quantities found have much less significance than the wide difference between the amounts where lime is lacking and where it is present.

When lime is applied to prevent the injurious effects of sulfate of ammonia, it should be borne in mind that the lime is not a quickly soluble substance but is very slow to dissolve in water. Hence it must be thoroughly distributed throughout the surface soil so that the sulfate of ammonia is reasonably certain to come in contact with it. Long-continued fertilizer experiments clearly show that soil water has no appreciable movement sideways, and the boundaries between limed and unlimed areas are sharply defined.

An experiment where lime to the amount of four times the calculated chemical equivalent of sulfate of ammonia was applied to a small plot

showed that it was not enough two successive seasons. Therefore it is best to apply the lime generously in form of finely ground limestone or the fine hydrated lime, as has been done in Field A.

Comparative Effects of Nitrate of Soda, Sulfate of Ammonia and no Nitrogen.

As stated in the beginning of this bulletin, it was not planned to include the results obtained with other nitrogenous fertilizers, but it has seemed best at this point to present the summary of the comparative effects produced by nitrate of soda and sulfate of ammonia which was last published in 1916,[1] the figures in which were as follows: nitrate of soda, 100; sulfate of ammonia, 88.8; no nitrogen, 73.4. This summary includes all the yields on the respective groups of plots.

It has been shown in the preceding pages that liming the soil produces marked benefit with sulfate of ammonia. Therefore a special summary has been calculated in which the yields for the years 1898, 1899, 1900, 1905 and 1906, when the effects of liming were due to applications over the entire plots, have been combined with those of the limed portions obtained in 1914, 1915, 1917 and 1918. This combination produced the following comparison: nitrate of soda, 100; sulfate of ammonia, 91.6; no nitrogen, 70.

The comparative effects in 1919 and 1920 were: nitrate of soda, 100; sulfate of ammonia, 100; no nitrogen, 70. The improvement in the production by sulfate of ammonia is possibly due to the nature of the crops. Under favorable conditions and in the presence of lime, both corn and timothy respond to sulfate of ammonia; and with its long growing season, corn is especially adapted to use the substance.

Conclusions.

Sulfate of ammonia has been effective as a fertilizer when accompanied by an application of lime. In the absence of lime it has sometimes been injurious, due to the formation of soluble compounds of manganese, aluminium and iron. Injury has been greatest in dry periods when the lessened soil moisture becomes more concentrated with soluble salts.

Sulfate of ammonia has been particularly effective on the cereals — corn, oats, rye and millet — when these crops have not followed a clover crop. Potatoes have not been benefited by the sulfate of ammonia in these trials. Soy beans, when uninoculated, responded well to the ammonia; but its effects grew less as the root nodules increased in the later years. Clover has not been much benefited by the sulfate of ammonia, but mixed grasses in 1920 were much increased by it.

In general, the sulfate of ammonia has been about nine-tenths as effective as nitrate of soda, per unit of nitrogen.

---

[1] Mass. Agr. Expt. Sta., 28th Ann. Rept.

APPENDIX.

Comparative Yields of Sulfate of Ammonia and no Nitrogen, 1889–1918.

Year.	Crop.	No Nitrogen.		Sulfate of Ammonia.	
		Grain (Bushels).	Straw or Fodder (Pounds).	Grain (Bushels).	Straw or Fodder (Pounds).
1889	Corn,	9.4	3,952	20.2	3,213
1890	Oats,	31.3	1,897	33.7	2,137
1891	Rye,	19.3	3,133	22.0	3,415
1892	Soy beans, green,	–	14,430	–	17,850
1893	Oats,	40.5	4,103	28.7	4,580
1894	Soy beans, green,	–	4,520	–	6,470
1895	Oats,	38.4	2,473	45.5	4,077
1896	Soy beans, green,	–	11,430	–	18,110
1897	Oats,	23.0	1,233	37.6	3,217
1898	Oats,	21.4	900	34.9	1,500
1899	Clover hay,	–	3,520	–	3,670
1900	Potatoes,	209.0	–	211.0	–
1901	Soy beans,	27.6	2,383	29.3	2,633
1902	Potatoes,	178.0	–	177.6	–
1903	Soy beans,	12.3	1,192	14.4	1,343
1904	Potatoes,	139.8	–	146.0	–
1905	Oats and peas (hay),	–	4,350	–	6,383
1906	Corn,	46.0	5,717	73.2	5,560
1907	Clover hay,	–	3,000	–	2,590
1908	Clover hay,	–	4,230	–	3,590
1909	Clover hay,	–	3,620	–	4,360
1910	Clover hay,	–	6,730	–	7,010
1911	Corn,	71.7	5,133	74.5	4,666
1912	Corn,	69.5	5,116	79.9	5,133
1913	Japanese millet (hay),	–	6,900	–	11,200
1914	Oats (hay) (unlimed),	–	1,420	–	2,160
1914	Oats (hay) (limed),	–	2,530	–	3,530
1915	Clover hay (unlimed),	–	8,130	–	7,300
1915	Clover hay (limed),	–	8,050	–	8,870
1916	Japanese millet,	28.5	5,234	26.5	5,506
1917	Potatoes (unlimed),	201.0	–	215.0	–
1917	Potatoes (limed),	333.7	–	322.3	–
1918	Corn (unlimed),	28.7	2,433	27.0	2,317
1918	Corn (limed),	31.3	3,400	39.3	4,566

TECHNICAL BULLETIN No. 4.

DEPARTMENT OF BOTANY.

DEVELOPMENT AND PATHOGENESIS OF THE ONION SMUT FUNGUS.[1]

BY P. J. ANDERSON.

I. Introduction.

Onion smut is the most destructive of all onion diseases in New England. In the Connecticut Valley it is probably responsible for more loss to the growers than all the other diseases of this crop combined. Despite the fact that a method of control by the use of formaldehyde has been developed, many fields are now planted to other less profitable crops on account of the ravages of smut; every year sees fields plowed up because smut has so reduced the stand that it is not worth while to tend them: more important in the aggregate, perhaps, is the smaller toll which the disease exacts from each onion grower throughout considerable sections of the valley.

Investigation of the disease with the primary object of finding better methods of control was begun by the Department of Botany of the Massachusetts Agricultural Experiment Station in 1918, and has been continued to date. Since control measures are necessarily conditioned by the normal life history of the pathogene, and since a review of the published research of other investigators showed that the development of the fungus had been inadequately studied, this phase of the problem has been made the subject of no inconsiderable part of the writer's study. Results of the work which deals directly with control are to be presented in another publication. The present paper concerns certain phases of the life cycle of the causal organism (*Urocystis cepulae* Frost) in which it seemed to the writer that further investigation was desirable. Beginning with germination of the spores, the development of the fungus will be followed through its saprophytic stage, infection of the host, distributive stage within the host and final sporogenesis.

[1] This paper embodies the results of preliminary and fundamental work on a project having for its chief aim the control of onion smut. A report on the more practical phases of this project is to be published shortly.

II. Germination of the Spores.

The spore of *Urocystis cepulae* is compound, having one large central fertile cell to the surface of which are attached 15 to 40 smaller hemispherical sterile cells. There are said sometimes to be two fertile cells at the center, but in a three-year study of the fungus the writer does not remember ever having seen a spore with more than one. To conform to the nomenclature of certain other genera of smuts, the entire structure is usually called a spore ball, the peripheral cells being termed pseudospores. Since we have here only one cell capable of germination, it is perhaps better to term the whole structure a spore and then distinguish between fertile and sterile cells. The hemispherical cells are attached to the fertile cell by their flat surfaces, but do not cover it entirely. They stand apart as indicated in Fig. 1 (page 109). The sterile cells are tinted brown, while the central cell is a more solid opaque brown. Sterile cells average 5μ in diameter by 4.25μ in height. The fertile cell is usually spherical, but frequently oval or ovate, averaging about 12μ in diameter. The entire spore averages about 19μ in diameter.

For the germination of most fungous spores it is only necessary to place them when mature in a drop of water, and, after a few hours, or, at most, a few days, the whole process may be watched under the microscope. But for *Urocystis cepulae* the case is not so simple. Germination tests, conducted in the same way in which the writer had brought to germination the spores of many species of fungi, were entirely without result for the onion smut fungus. Apparently there are other essential conditions which had not been obtained in these trials. This preliminary failure led to a thorough search through the literature to find what conditions were essential for the germination of spores of other species of Ustilaginales. It seemed probable that the same conditions which brought about germination in other smuts might also be successfully applied to *Urocystis cepulae*. A condensed summary of the literature of this phase is given below, followed by a description of the experiments with the spores of *Urocystis cepulae*.

Review of the Literature on Essential Conditions for Smut Spore Germination.

The Water Requirement.—No spores will germinate without water in some form, sometimes, to be sure, merely as vapor in a saturated air. In the simplest cases, and, in fact, for the majority of the smut fungi, it is only necessary to immerse the spores, as soon as mature, in a drop of water on a slide, or in a hanging drop. Enough air to satisfy all requirements seems to be present dissolved in the water, or else the spores remain on the surface of the drop. Brefeld (3), in his experiments, germinated the spores in a film of water which adhered to the inside of the walls of flat glass chambers after the bulk of the liquid had drained out. This probably insured greater access to air than where the hanging drop or drop on slide has been used, and this fact should be kept in mind in interpreting his results.

The following species can be germinated in water as soon as mature: *Cintractia densa* McAlp. (11); *C. Sorghi vulgaris* (Tul.) Clint., 12 hours,[1] (11); *Entyloma canescens* (14); *Schizonella melanogramma* D. C. (4); *Sorosporium Reilianum* (Kühn) McAlp., tap water, 17 hours (11); *Tilletia zonata* Bref. (4); *Urocystis occulta* Wallr. (11); *U. primulicola* Magn., 10 hours (14); *U. Violae* Sow. 5 days (4); *Ustilago Avenae* (Pers.) Jens., 6 to 8 hours (8), (11) and others; *U. Bouteloudae humulis* Bref. (4); *U. Carbo* Tul., 6 to 10 hours (5); *U. flosculorum*, 5 to 6 hours (7) (he finds that fresh spores germinate most quickly); *U. grandis* Fr., 24 hours (3); *U. longissima* Sow., 3 to 4 hours (3), (7); *U. major* 24 hours (14); *U. Panici glauci* Wallr., 8 days (3); *U. Readeri* Syd. (11); *U. segetum*, 6 to 8 hours, "fresh spores germinate better" (14); *Ust. violacea* Pers. (3) and many others. In the most favorable cases germination begins within two to three hours, while at the other extreme McAlpine (11) mentions species the spores of which did not begin to germinate until they had been in water for several weeks. Where such extreme lengths of time are required, the question arises as to whether this is not really the time required for the weathering process such as takes place when they are kept in damp soil, as in Brefeld's experiments.

Air. — Some spores require only a moist air for germination, and will not germinate at all or only abnormally when immersed in water. Thus Fischer von Waldheim (7) writes: —

> For the normal germination of the different species of Ustilago, a certain quantity of water or moisture is usually necessary. For this purpose, the spores need only be placed in a drop of water, or upon moistened earth, or even merely in an atmosphere kept moist; for instance, under a glass globe placed over a dish of water. But Tilletia and Urocystis germinate only in damp air (for instance, under the glass globe mentioned), and their germinating spores, coming in contact with water, only show abnormal appearances.

In Brefeld's germinating apparatus the spores were never entirely immersed in water, but in the thin film clinging to the chamber walls must have always had a sufficient quantity of air. This probably contributed to his remarkable success in germinating the spores of a very large number of species. McAlpine also found that he was able to secure germination in many cases only by floating the spores in a watch glass over water. Both Brefeld (3) and Fischer von Waldheim (7) mention the fact that the spores of *Tilletia caries* germinate in damp air. Plowright (14) had a similar experience with *Tubercinia trientalis*. McAlpine (11) was able to germinate the spores of *Tilletia Tritici* (Bjerk) Wint. best by keeping them on moist filter paper or blocks of plaster of Paris kept moist by capillary water from a dish in which the blocks were partially immersed. He (11) makes the following interesting observation on the necessity of air for germination of spores of *Ustilago Readeri* Syd.: —

---

[1] Figures after the species and not in parentheses indicate the time required for germination to begin after the spores were placed in water. Omission of them indicates that the investigator gave no data as to time required. Numbers in parentheses refer to bibliography on pp. 132 and 133.

Immersed in the liquid they do not germinate as readily as when floating on the surface. Thus, after eighteen hours on one occasion, the spores in the water had failed to germinate, while by simply altering the focus and examining the spores on the surface they were all found, with very few exceptions, to have germinated.

In the descriptions of germination given by the majority of writers there is no way of determining just how much influence the presence of air had.

It seems probable that, in general, the presence of air is essential to the germination of smut spores, but that different species vary in respect to the amount required; some need scarcely any, others must have very free access to air, and there are probably all gradations between these two extremes.

Nutrient Solutions. — Very early in the investigation of smut spore germination it became apparent that the spores of some species could not be germinated merely by placing them in water when mature. Consequently solutions of various substances supposed to have nutritive qualities have been tested for their ability to induce germination. Hallier (6), in 1868, was apparently the first to use such solutions. He used a great many substances such as albumin, starch, milk, sugar solution, etc. Others, since then, have used almost every kind of a salt, acid, or other substance for which one could imagine any germinative influence. One should consult Osner's (13) bulletin on "Leaf Smut of Timothy" to gain some idea of the number of substances that can be used for that purpose. McAlpine (11) seems to have had most success with a hay infusion, although he also used various other solutions. Sugar solutions and decoctions of the host plant have proved fairly successful.

The nutritive solution which has been used most extensively and probably most successfully is the "nährlösung," a sterilized aqueous decoction of horse dung which was employed first by Brefeld (3, 4). In this "nährlösung" he was able to bring to germination the spores of many species which showed no sign of germination in water, *e.g.*, *Cintractia spinificis* (Ludw.) McAlp. (McAlpine (11) also confirmed Brefeld's results), *Doassansia Limosellae* Kunze, *Ustilago Andropogonis tuberculati* Bref., *Ust. Arundinellae* Bref., *Ust. Coicis* Bref., *Ust. Cynadontis* Hem., *Ust. Ischdemi* Fckl., *Ust. major* Schroet., *Ust. Panici leucophaei* Bref., and *Ust. Tulasnei* Kühn. Other species, *e.g.*, *Ust. Maydis*, which gave scanty or only occasional germination in water, germinated to almost 100 per cent in this "nährlösung." In almost every case the growth and size of the germ tube (promycelium) was increased; and frequently sporidia were produced in this nutritive solution where none at all were developed in water. On the whole, however, it should be kept in mind that in by far the majority of cases the function of the nutritive solution was to bring the germling to complete development after it had started, rather than to cause it to start in the first place. Only in the case of the comparatively few species mentioned above did he fail to get some germination in water also, and very commonly the percentage of germination was as high in water as in "nähr-

lösung." On the other hand, he found that *Tilletia Tritici* would not germinate at all in nutritive solution, but could be germinated easily in water.

His experiments with nutritive solutions led Brefeld to believe that smut spores in the soil are brought to germination and further development through the influence of manure which has been used to fertilize the soil. On this theory he explains the common observation of German farmers that cereal smuts are more destructive on freshly manured fields.

Host Stimulus. — One might expect that some stimulus from the host plant would be necessary for germination, and consequently that a decoction from the host, or the presence of bits of it in the germinative medium, would be necessary for starting germination. Although such host decoctions have been successfully used, we find in the literature no instance in which they furnished the only conditions under which the spores would germinate. There seems, then, to be no evidence to indicate that a smut spore must be in close proximity to, or in actual contact with, its host before it will germinate.

Period of Rest. — But, even with the aid of nutritive solutions, and all other conditions which have been tried, there is a considerable number of species, the spores of which cannot be brought to germination immediately after maturity. For these species, a period of "rest" is necessary during which they must be exposed to certain natural conditions which operate in some way to bring them into the proper condition for germination. For our knowledge of this phase of the problem we are indebted, above all, to Brefeld, and we cannot present it better than by quoting from his summary of it ((4), page 128):[1] —

> Only a part of these forms germinate at once even in nutrient solution, more rarely in water; many will not germinate at all, but must be made capable of germination by special methods. . . . The spores of many species are so adapted in their time of germination that they do not proceed at once, but only after passing through a shorter or longer resting period. In cases of this kind one has only to wait until after the expiration of the resting period in order to bring them to germination. But one would often wait long and in vain, if he only kept the spores dry in the house. Under these circumstances, the external influences are not brought to bear, which operate in nature during the period of rest, and which must operate in order to bring about those changes on which the initiation of germination depends. For the most part, when simply kept dry the spores die without germinating, except in a few cases, as, for example, the corn smut, . . . but even here germination is always incomplete. It is necessary to obtain the conditions which in nature operate on the spores and influence them to germinate, if one wishes to succeed in observing germination. The simplest method would be to expose the spores in nature or leave them in their natural habitat and observe from time to time whether germination has begun. But in most cases it is entirely impossible in this way to get and keep the material pure.

He then describes in detail his method of keeping the material in sterilized damp sand in pots in a cool cellar. Then he continues: —

---

[1] Translated by P. J. Anderson.

By this method it has been possible to bring to germination most spores which otherwise would not germinate. The length of time required to bring about germination varies greatly. The spores of some species usually germinate after a few months, others after a half or an entire year, others require several years before germination, some even five years. . . . In this methodical way, which is, to be sure, nothing but an imitation of what takes place in nature, ultimately all spores can be induced to germinate. Therefore it can be scientifically proved that the earlier or later germination is only an adaptation, a resting period, which under the natural conditions must be passed through, if the inner and apparently chemical changes are to operate, through which the germination of the spores is slowly prepared and finally made possible.

In this way Brefeld was able to germinate the spores of the following species none of which would germinate when first mature (length of time in moist earth given after each): *Anthracoidea* (*Ustilago*) *Caryces* Bref., over winter; *Anthracoidea subinclusa* Bref., 1 year; *Doassansia Alismatis* Nees, 1 year; *D. Limosellae* Kunze, 1 year; *D. punctiformis* Niesse, more than a year; *D. Sagdlariae* Fckl., over winter; *Melanotaenium cingeus* Bref., 4 years; *Neovossia Barclayana* Bref., 2 years; *Sphacelotheca Hydropiperis* Schum., 6 months; *Tilletia controversa* Kühn, 2 years; *Tilletia decipiens* Pers., 3 years; *Tolyposporium bullatum* Schroet., 9 months; *Tol. Junci* Schroet., 6 months; *Tol. Penicillariae* Bref., 1 year; *Urocystis Anemones* Pers., 6 months; *Ur. Filipendulae* Tul., 1 year; *Ustilago Adoxae* Bref., 1 year; *U. anomola* Kunze, over winter; *U. Bistortarum* D. C., 1 year; *U. Coicis* Bref., 2 years; *U. domestica* Bref., 6 months; *U. Holostei* D., 3 years; *U. utriculosa* Nees. Other writers also have found that for various species, a weathering under natural conditions was necessary in order to secure germination.

Substitution of Nutritive Solution for Weathering Period. — In the case of some species Brefeld believes that the same changes which are ordinarily induced by storage in damp soil for a long period may be induced at once by the use of his "nährlösung." For example, he finds that the corn smut spores when first mature will not germinate in water, but if kept until the following spring they germinate in water. If, however, the freshly matured spores are put in nutritive solution, they germinate overnight almost without exception. He concludes, therefore, that the changes induced by one are the same as those induced by the other, or, in other words, that each may be substituted for the other.

Freezing. — Whether or not freezing has any influence on germination seems never to have been determined. Brefeld makes no mention of freezing, and one infers from his publications that his buried spores were never frozen. Since the spores of practically all species of smuts have been successfully germinated without freezing, it may be safely said that freezing is not a necessary condition of the process.

Essential Conditions for Germination of Urocystis cepulae Spores.

Search through all available literature on the subject revealed only one reference to previous attempts at germination of the spores. Thaxter (18) was unable to germinate fresh spores either in water or in moist air. When,

however, the smutted onions were stored until January, then mixed with wet earth and frozen for a week or more, the spores germinated when kept moist in a warm room. They also germinated in an onion decoction. He also made pure cultures in onion decoction from fresh spores and from sporiferous hyphæ, but does not mention germination in this respect. Such, in full, is the extent of our present knowledge of the necessary conditions. The purpose of the writer's experiments was twofold: (1) to duplicate Thaxter's work and (2) to extend the inquiry in order to determine more exactly many points which Thaxter either did not touch or treated insufficiently. The experiments are summarized below.

Fresh Spores in Water. — Spores from a fresh but mature lesion were scattered in a drop of water on a slide kept in a Petri dish with water in the bottom of the dish to prevent evaporation of the drop on the slide. This common and familiar method was used in all the experiments where water or a water solution was tested. Both distilled water and tap water were tried. The spores were examined daily for over two weeks, but no indication of germination was observed. The experiment was repeated many times, and the temperature and light relations were varied in different sets, but always without result. Spores taken from lesions which had been kept dry for a year in the laboratory gave no better results.

Fresh Spores in Soil Water. — A soil extract was made by filling a beaker with good onion soil (taken from a field where smut was abundant), adding water until the soil was saturated and the water was 1 cm. deep on top of it, stirring thoroughly several times and filtering off after several days. Results were the same as with tap and distilled water.

Influence of the Germinating Onion Seed. — These tests were in every way like those described above with water, except that a few germinating onion seeds were placed in each drop in addition to the spores. With one exception, in these tests the spores failed to germinate. On one slide a very few spores germinated in close proximity to the young cotyledon.

Fresh Spores in Soil Decoction. — A mixture of soil and water was cooked for one hour on two successive days in the autoclave at 14 pounds' pressure, filtered, tubed and sterilized. It was hoped that in this way more of the soil substances would be brought into solution, and that they might bring about germination. But, just as in the case of the soil extract, so with this more concentrated soil decoction, there was no germination.

Fresh Spores in Dung Decoction. — This decoction was prepared just as Brefeld prepared his "nährlösung" which he used so successfully on the spores of a large number of species. Fresh spores failed to germinate in it. In these experiments the solution was concentrated. It is possible that if it had been more diluted the results might have been different.

Fresh Spores in Onion Decoction. — This decoction was prepared by boiling a sliced onion in a pint of water for one hour. It was then filtered, tubed and sterilized one-half hour at 15 pounds' pressure. This appears to furnish an excellent medium for the growth of bacteria and fungi, and in working with it every possible precaution must be used to prevent contamination. These organisms grow so fast that they soon obliterate the

more slowly germinating smut spores. It was found necessary not only to sterilize, by boiling, the slides, Petri dishes and all instruments used, but also to wash the seedlings from which the spores were taken, first, in mercuric chloride, 1 to 1,000, and then in sterile water, before the lesions were opened. In drops of this decoction some of the spores began to germinate within three days at laboratory temperature. The percentage of germination, however, was always very low. In dozens of slide tests made in this way, not over 25 per cent germination has ever been observed; and in most cases it is lower, averaging 5 to 10 per cent. It is apparent from these tests that there is some substance in the onion which is capable of inducing germination of fresh spores. In the light of other tests described below, however, one would not be justified in concluding that this substance is peculiar to the onion alone.

Fresh Spores in Sugar Solutions. — Sterile solutions of ½, 1, 2, 3, 5, 7 and 10 per cent cane sugar were used just as the onion decoction mentioned above. There was some germination in all of them, but very little in the ½ per cent and the 10 per cent. The highest percentage of germination was in the 2 per cent solution, where 50 per cent of the spores *which were on the surface of the drop* germinated. When spores are mixed with a water solution of any kind, some of them remain on the surface while others sink to the bottom. Only a very small percentage of those which were immersed germinated. Since the spores on the surface are better located for obtaining air, it is apparent that air is an important factor in germination. It is also apparent that sugar is at least one of the substances which may induce germination. Since onions contain a high percentage of cane sugar, it seems probable that this is also the effective element in the onion decoction which induces germination.

Fresh Spores on Onion Decoction Agar. — Onion decoction agar was prepared by adding 2 per cent of agar to the onion decoction. Sterile plates were poured and permitted to become hard. Spores were mixed with onion decoction or water and floated over the surface of the hard agar. After permitting the spores to settle to the bottom the liquid was poured away and the spores were left distributed over the agar. This insured a sufficient quantity of air, and at the same time access to nutrient substances in the agar. The percentage of germination varied with different experiments, but always it was as high as 10 per cent; sometimes 50 per cent. This was found to be the most reliable of all the methods and was largely used. Here also it was noticed for the first time that the spores did not all germinate on the same day, but that there was a progressive germination, new ones starting each day for as long as three weeks, after which the plates had dried too much, or possibly the supply of food had become exhausted.

Fresh Spores on Czapek's Agar, Sugar Potato Agar, etc. — The Czapek's agar contains 3 per cent of cane sugar. Several other agars containing sugar were tried and always with a small percentage of germination, but none higher than on onion decoction agar.

Fresh Spores in Soil Decoction Agar. — After the rôle played by air was determined, it seemed that the writer's previous failure to induce germination in soil decoction might have been due to exclusion of air. Therefore a medium was prepared by adding 2 per cent of agar to the soil decoction. Tests were made as with the onion agar, using soil decoction, however, for floating the spores over the surface. After five days, germination of 1 to 2 per cent was observed. With each day, however, more of them germinated, and this continued for several weeks until the plates became too dry or were exhausted. We may conclude from these experiments that (1) the soil contains all the essential stimulating elements for germination, and (2) not all the spores germinate at once, but there is a progressive preparation.

Fresh Spores on Dung Decoction Agar. — This medium was prepared by adding 2 per cent of agar to the dung decoction mentioned above. Since the soil used in making the soil decoction had been heavily manured during the previous season, it was thought that some element in the manure might furnish the stimulus and a higher percentage of germination would be secured. The percentage of germination in this medium, however, was scarcely as high as for the soil decoction. Here is proof, however, that stable manure contains some substance which is capable of inducing germination.

Effect of Freezing the Spores. — It has been previously mentioned that Thaxter froze smutted mature onions in the soil and then found the spores capable of germination. This experiment was duplicated as nearly as possible by the writer, but he was entirely unable to get the spores free from bacteria and other fungi, and abandoned the method rather than work with contaminated cultures.

An attempt was next made to freeze the spores under sterile conditions. Smutted seedlings were sterilized with mercuric chloride 1 to 1,000, washed in sterile water, and sealed in sterile test tubes with a drop of water in the bottom of each tube. After being exposed for nine days during December, during which there were some light freezes, they were tested in onion decoction. There was a germination of about 2 per cent. In similar tests during January, in which they were frozen solid for ten days or more, buried under the snow in zero weather, the spores were apparently killed. No germination at all was observed, although tried on or in the various media described above. In view of the fact that the mycelium in culture is not killed by freezing, these results are difficult to explain. In a later series of tests smutted seedlings, sterilized on the surface, were buried in sterile soil in test tubes and then frozen out of doors for eight weeks. On onion decoction agar plates, varying percentages of germination were then secured, but it was never as high as for spores which had been kept in damp soil during the same length of time, but not frozen. The conclusion seems warranted that freezing does not kill spores in the soil, but it does not render them more capable of germination, and is not necessary.

Effect of a Period of Rest in Damp Earth. — Seedlings with unopened lesions were sterilized and buried in sterile soil in test tubes. The tubes

were then sealed and kept in the laboratory. After two weeks, germination was found to be somewhat higher than in the case of spores from fresh lesions. Tests at the end of four weeks gave 50 per cent germination. At the end of three months the average percentage was not higher, though in individual slides it mounted to about 65 per cent. A higher percentage of germination has not been seen in any test. In removing these seedlings from the damp earth it was constantly noticed that the soil remained clinging to the lesions and could be washed off with difficulty, while it was very easily removed from other parts of the plant. Microscopic examination showed that the soil particles were attached by numerous fungous hyphæ. When these hyphæ were transferred to sterile agar tubes they gave pure cultures of Urocystis. It was not possible to determine whether these hyphæ arose from germination of spores in the sori, from vegetative hyphæ in the seedling or from both. If the spores germinate while still inside the lesion, this may explain why not all the spores taken from the weathered sori germinate; they may have already germinated. This experiment demonstrates clearly one way, at least, in which the smut mycelium gets back into the soil from the diseased plants.

Natural Conditions of Germination. — It is a common impression among laymen that the spore remains dormant in the ground, lying in wait until an onion starts to grow near it, upon which it germinates and infects the onion. Such, however, is apparently not the case. The seedling does not seem to furnish any stimulus which causes the spore to start. Whatever substances are necessary for starting the process are in the soil itself. As soon as the spores are released into the soil — if not before — a few of them germinate; the others become capable of germination gradually, and it seems likely that all of them finally come to germination, but that the period of preparation differs in length for different spores, so that the germination extends over many months and possibly years. This period of preparation may be shortened artificially by the use of certain stimulating substances, such as cane sugar.

The Process of Germination.

Germination begins in three to six days after the spores are placed in the water solutions or on agar plates as previously described. The time varies somewhat with the medium used, and also apparently with other factors which have not been explained. Three days are usually sufficient in onion decoction or onion agar, while on soil decoction agar six days were found necessary.

The first indication of germination is the appearance of a hyaline hemispherical vesicle (Fig. 1, B) on one side of the spore. This is apparently an extrusion from the central fertile cell, but whether it comes out by a rupture of the spore wall or by a regular pore could not be determined. The covering of sterile cells renders exact observation of this point difficult. This vesicle when first observed is of about the same size as one of the sterile cells, and can at first be distinguished from the latter only by the

fact that it is hyaline while the sterile cells are brown. During the succeeding stages, however, it increases rapidly in size until it may be almost as large as the spore itself (Fig. 1, K). This hemispherical or subglobose

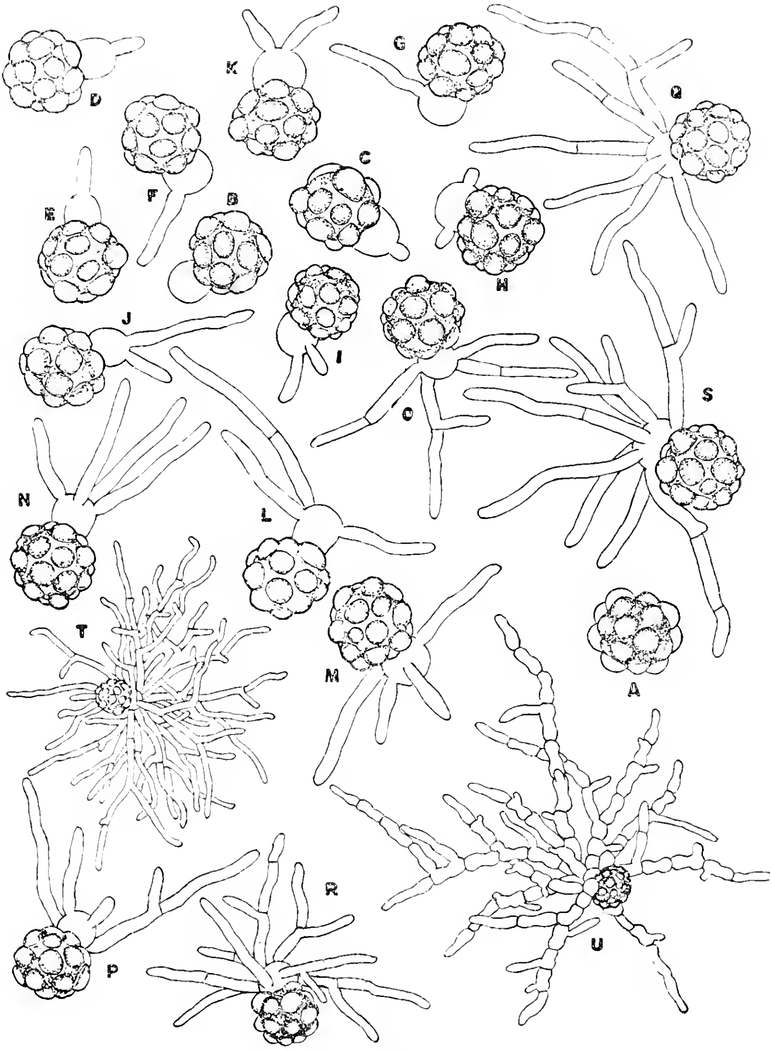


FIG. 1. — Germination of spores.

vesicle corresponds to the promycelium or hemibasidium of other smuts and rusts, and will be so designated. A stout tube grows out from the surface of the promycelium (Fig. 1, C–G) and is quickly followed by others in succession until a whorl of diverging branches is produced (Fig. 1, H–N). The number of branches in the whorl is not constant, neither

do they arise simultaneously but usually in succession. None has been observed, however, which showed more than eight branches on a promycelium (Fig. 1, S). These primary branches are 2 to 3μ in diameter, usually somewhat undulating, with broadly rounded tips. They soon become septate, and almost invariably a lateral secondary branch grows out from the top of the cell just below each septum (Fig. 1, O–S). The angle of divergence between the primary and secondary branch is very broad, often approaching a right angle. This manner of branching is characteristic of onion smut mycelium wherever it is found, and is a good diagnostic character. By continued branching, a dense mass of mycelium is developed about the spore, and it becomes increasingly difficult to follow the course of single hyphæ. Fig. 1, T, represents the latest stage in which the separate branches could be followed. On agar plates the older cells lose their dense protoplasmic content, and only the more distant tip cells appear to be alive. In onion decoction, as the hyphæ become older they become more constricted at the septa and the cells rounded in the middle until they appear almost separated from each other, the hypha having somewhat the appearance of a string of beads (Fig. 1, U). Frequently in the older mats of mycelium from the germinated spore it has been observed that some of the hyphal tips are recurved in the form of croziers. They have, however, never been seen to develop further, and it is impossible to say whether this development has any relation to development of spores, which are never produced except inside the tissue of the host. In hundreds of germination tests which have been made during three years in a large number of media, no conidia have ever been observed on the promycelium or its branches or anywhere else throughout the development of the organism. Sometimes the short lateral branches appear like conidia, but continued observation soon convinces one that they are merely vegetative branches which will elongate apically like other branches unless the supply of nutriment is exhausted.

Comparison with the Germination Process in Other Species of Urocystis.

Let us now compare this process with the process of germination which other investigators have described for other species of Urocystis.

Urocystis occulta Wallr., causing the flag smut of rye, was apparently the first species of this genus which was studied with respect to germination of spores, that process having been first observed and described by Kühn in 1858. It was later studied by Wolff (19), Brefeld (4), McAlpine (11) and others. According to Brefeld a promycelial tube of varying length is first produced, and at its apex it branches verticillately into a whorl of four to six branches. These branches increase in length by apical growth, and they, as well as the promycelial tube, become progressively septate, while the protoplasmic content of the older cells constantly disappears and the only living cells are those at, and just back of, the growing tips. The verticillate branches never produce conidia, but form mycelium by continued growth. McAlpine considers the verticillate branches them-

selves as conidia, but does not state that he ever found them detached. This resembles the process in *U. cepulae* in (1) the production of the whorl of branches, (2) the complete absence of sporidia and (3) the progressive emptying of the cells. The main point of difference is in the elongated, ultimately septate, promycelium in *U. occulta* which replaces the globose vesicle of *U. cepulae.*

In *U. Tritici* Koern. the process is almost identical with that of *U. occulta* according to McAlpine (11), but the promycelium is at times unicellular, a condition which suggests that of *U. cepulae.*

The germination process in *U. Anemones* (Pers.) Wint. has been studied by Fischer von Waldheim (7), Plowright (14) and Brefeld (4). As described and figured by Brefeld it is almost identical with the process which the writer observed in *U. cepulae* except that the promycelium is not so large. The whorl of 2 to 4 branches arises very close to the surface of the spore on a very much reduced promycelium, and they remain permanently sterile.

In *U. Filipendulae* Tul. (Brefeld (4)) the whole process is identical with that of *U. Anemones.*

Germination of the spores of *U. Violae* Sow. has been studied by Prillieux, Dangeard, Brefeld (4) and others, being a favorite subject for study because of the ease with which germination can be brought about in water. Each fertile cell of the spore ball produces an elongated promycelium which becomes septate just as in *U. occulta*. A whorl of three to eight diverging branches is produced at the apex. Each verticillate branch grows out at the distal end into a slender sterigma on which is borne a long cylindrical conidium. In nutrient solution these primary conidia may produce secondary or tertiary conidia. The process in this species differs from that of *U. cepulae* (1) in the length of the promycelium, and more especially (2) in the development of conidia.

In general, then, we may conclude that *U. cepulae* differs in its germination from the other species of Urocystis (except *U. Violae*) only in theshape of the promycelium which is here reduced to a nonseptate hemispherical vesicle. All other details of development appear to be identical.

Comparison with the Process as described by Thaxter.

As described and figured by Thaxter the spores germinate by a single long irregularly branched tube on the tips and lateral branches of which are borne small ellipsoidal to long ovoidal conidia. He does not mention a globose promycelium or whorl of branches such as the writer has always observed. The marked differences in the process as observed by the writer and as described by Thaxter are difficult to explain, unless they are due to contamination in the cultures used by the latter. He states that he was unable to obtain the material pure, and that "all the cultures swarmed with bacteria." The presence of these same bacteria might produce a difference in the development of the germination process. The writer in attempting to secure germination by Thaxter's method also failed to keep the spores free from bacteria and therefore changed to a different method.

III. Saprophytism.

The early botanists and mycologists believed that smut fungi were obligate parasites, *i.e.*, they developed only when in parasitic relation with host plants from the living cells of which they must take their nourishment. We now know, however, that at least most smut fungi have in their life cycle a saprophytic period during which they may develop extensively and propagate for a long time, deriving nourishment only from dead organic material in the soil or other substrata. Also most of them may be propagated indefinitely in artificial culture media of various compositions. Our knowledge of this stage began with the extensive investigations of Brefeld (3), and has been increased later by numerous smaller contributions from a large number of workers. *Urocystis cepulae* is no exception to the rule, and is very readily isolated and grown in a large number of culture media and on soil. It is probably able to exist and grow in the soil for years in entire absence of onions.

Isolation.

Two methods of isolation have been used by the writer. By the first method a germinating spore on an agar plate is located under the microscope by a ring of India ink, care being taken that this spore is far enough removed from all others to prevent confusion. When the mycelium from the germinating spore has increased to such an extent that it is visible to the naked eye as a tiny white speck it is transferred to an agar slant where it gradually spreads to the agar of the tube and can be grown for a long period. This method was used especially in the original isolations when it was necessary to know for certain that the resulting fungus originated from a single spore of *Urocystis cepulae*. In later work a more rapid method was used. A part of a cotyledon or young leaf containing a lesion which had not yet broken open was washed for a few minutes in mercuric chloride 1 to 1,000 and then in sterile water. The lesion was then cut into as many pieces as desirable and the pieces transferred to agar slants. One hundred per cent of pure cultures could be obtained in this way. Lesions of any age could be used, but the youngest were found to be most satisfactory.

Cultural Characters.

The range of media on which the fungus will develop is almost unlimited. Those which the writer has used are listed below along with a brief statement of the peculiarities exhibited by the organism on that particular medium.

Potato Agar.

The ordinary potato agar containing a boiled decoction from a large potato and 17 grams of agar to a liter of water. No sugar was added and the acidity was not determined. Growth very slow, reaching a diameter of 1 cm. in about ten days; very dense and compact like fine felt, snow white, dry, flat, but with considerable

aerial mycelium; margin very definite and even. After about ten days the mycelium shows more and more of a tendency to grow beneath the surface of the agar, and the edge has the appearance of gradually fading away into the surrounding agar. Growth may progress for several weeks, but is gradually checked by the drying out of the agar. Some of the cultures show indistinct zonation. With age the surface of the felt may become rugose.

Oat Agar.

Growth more luxuriant than on potato agar, showing denser zones of white mycelium. No change of color in mycelium or in the medium. Growth not sufficiently different from that on potato agar to have any diagnostic value.

Nutrient Beef Broth Agar.

The standard agar of bacteriological work. Growth scanty, much less than on potato agar, slimy, and taking on the color of the medium; never dry, very little aerial mycelium. A very poor medium for growing the organism.

Czapek's Agar. [1]

This was found to be a very favorable medium, the growth being more rapid and with a greater abundance of white, cottony aerial mycelium than on potato agar. After about two weeks the agar below the growth, especially in the upper part of the tube, turns maize yellow, [2] due to the suffusion of a pigment. After about four weeks the color becomes more intense — aniline yellow or citrine yellow. With age this darkens to orange citrine or to various shades of olive. Also the mycelium as seen from above loses its white color after three or four weeks, showing various shades of greenish yellow — citrine drab, olive lake, etc. These color changes on Czapek's agar offer one good diagnostic character.

Onion Decoction.

Prepared by boiling a sliced onion in a liter of distilled water and sterilizing the filtered product for one hour at 15 pounds' steam pressure. Growth very slow, resulting in development of little compact balls of mycelium; brown when in the bottom of the tubes or white when on the surface of the liquid. Growth continues for months very slowly, but the little balls of mycelium do not attain a diameter of over 1 cm.

Onion Agar.

Prepared exactly like potato agar, but the onion decoction as described above is used instead of potato juice. This was found to be not only the best medium for culturing Urocystis, but also very much better than potato agar for growing many other fungi which the writer had occasion to try on it. It is very easily prepared, has a minimum of sediment even when not filtered, and altogether forms a very superior general purpose agar. Its only objectionable qualities are the obnoxious odor in the laboratory during preparation, and the fact that the growth of certain fungi is too luxuriant for some purposes. The growth starts with a dense white felt much like that on potato agar, but more rank. After about a week wrinkles begin to appear near the center, and these spread and become sharper and the irregular ridges more elevated with age, also at the same time the crests of the ridges become hygrophanous and gray. This appearance spreads until it involves

---

[1] For method of preparation see Soil Science, 2:113.

[2] All colors according to Ridgway's Color Standards.

the entire center or wrinkled part of the growth. The convoluted gray growth on onion agar is perhaps the best diagnostic cultural character of the species. It has been very constant in the many series of cultures which the writer has made with this agar. After a few weeks the color in reverse becomes darker, reaching cinnamon brown in about five weeks.

Sugar Potato Agar.

Prepared as potato agar with the addition of 3 per cent of saccharose. Growth is coarser in texture, more luxuriant and spreads more rapidly than on potato agar. The aerial mycelium is not snow white, but early assumes a cream color changing to cartridge buff after a few weeks.

Effect of Concentration of Sugar on Growth of the Mycelium in Culture. — In the series of cultures on different media it was observed that the best growth occurred on media containing considerable sugar, viz., Czapek's, sugar potato and onion agar. This led the writer to suspect that sugar is the essential element of nutrition both in culture media and on the host itself, since the onion contains a high percentage of saccharose. In order to determine the effect of sugar on the development of the organism, Czapek's synthetic agar was prepared first without any sugar and next with .5, 1, 2, 3, 5, 7 and 10 per cent of cane sugar. Five tubes of each were inoculated at the same time and accurate notes taken each day. No growth whatever occurred where no sugar was included. At the end of three weeks there was very little difference in the diameter of the growths on all the other concentrations, but those on the higher concentrates were a little more dense. The most apparent difference was in the color which was imparted to the agar. In the .5 per cent the culture was pure white in reverse, while in the 10 per cent it was bright yellow. The other concentrates formed a perfectly graded series between the two. The only other difference noticed was a wrinkling of the surface of the growth in some of the higher concentrates, and its entire absence from the cultures of low sugar content. Certain conclusions seem warranted from this experiment: (1) agar and inorganic salts alone do not furnish food for growth; (2) the yellow color in the agar is due to some reaction with the sugar; (3) the amount of growth (at least for three weeks) does not depend on the amount of sugar present. Any one of the concentrates apparently contained more than the maximum amount which the organism could utilize.

Substitution of Starch for Sugar. — In order to see whether the fungus can utilize starch as a source of carbon, agar tubes were prepared identical with Czapek's except for the substitution of soluble starch for saccharose. A scanty growth occurred, but even after four weeks it had not attained a diameter of 1 cm. and was very thin. Apparently, then, Urocystis can utilize starch, but it is a very poor source of carbon.

Soil Decoction Agar.

Prepared by adding 2 per cent of agar to the soil decoction described above. Growth was much less vigorous than on potato agar, and thin, but, on the other

hand, spread almost as rapidly over the surface for the first few weeks. There can be no question whatever but that soluble elements in the soil furnish sufficient food for the development of the mycelium.

Dung Decoction Agar.

Prepared by adding 2 per cent agar to the dung decoction previously mentioned. Growth much thicker than on the soil decoction agar, but not as heavy as on Czapek's, sugar potato, etc. Dense white aerial mycelium. The conclusion seems warranted that horse manure furnishes all the elements necessary for the growth of the fungus, and is more favorable medium than a good soil. Apparently a heavily manured soil would be more favorable for the propagation of smut than one which was not manured.

Tolerance of Acid. — Four series of cultures were made on onion agar, — the first series without lactic acid; second, with 1 drop of lactic acid per tube; third, with 2 drops per tube; fourth, with 3 drops. All were inoculated at the same time. Growth was rank and normal in the series in which no lactic acid was added; no growth whatever in the series in which 3 drops were added; a very slight growth where 2 drops were added; growth much retarded in the 1-drop series. This series was begun with the purpose of finding a method of excluding bacteria from cultures of the smut fungus, but the latter was apparently checked by acid just as much as the bacteria.

Effect of Freezing the Cultures.

Cultures on potato agar and on onion agar were kept out of doors for two months during the most severe winter weather of 1919–20. Transfers were then made to fresh agar tubes, and the mycelium grew luxuriantly and rapidly on the surface of the slants. In fact, the growth at first seemed to be even better than when transfers were made from cultures which had not been frozen. Accurate measurements on a second series showed a slight difference in favor of the transfers from frozen mycelium during the first few days, but it was not permanent. We may conclude, then, that freezing not only does not injure the mycelium, but possibly stimulates it to even better growth.

Microscopic Characters of the Mycelium in Culture.

The characters of the mycelium differ somewhat with the age of the culture. Microscopic examination of a culture a week old shows slender hyaline hyphæ of rather uniform diameter, about 2μ, with rather indistinct septa and homogeneous contents. Branches arise almost exclusively from the upper ends of the cells and diverge at a wide angle. The characters have not changed from the condition previously described under germination of the spores. Not all of the cells of the mycelium appear to be alive; some of them are empty and apparently dead; others are full of homogeneous protoplasm with no vacuoles. Under the oil immersion lens one notices certain very refractive granules scattered throughout the dense protoplasm (Fig. 2, A). The cells are easily broken apart, and when a

mount is made the hyphæ appear in segments as represented in the figure. At this early stage they show no constrictions at the septa. No conidia can be found. Clamp connections have not been observed.

If, however, cultures several weeks old are examined microscopically it will be observed that certain changes have taken place. The aerial mycelium may remain about the same as described, except that the cells appear vacuolated, but there will now be found a different kind of mycelium beneath the agar surface. These hyphæ are stouter, averaging 3.2μ in diam-

Fig. 2. — Details of hyphæ in culture. Detached hyphal cells at C and further development of same at D.

eter, the cells are much shorter, the septa very distinct, and the hyphæ decidedly constricted at the septa, so much so that the hyphæ appear almost like strings of separate cells. A large proportion of the cells become shaped like dumb bells. When disturbed, as in mounting, the cells of the thread break apart very readily so that when one makes a mount of an old luxuriant culture, such as on onion agar, he hardly finds mycelium at all, but only these irregular separate units. Most of them are branched at the tip. A strand of this mycelium is represented in Fig. 2, B, with a young ordinary hypha for comparison. The appearance of the separate cells from an onion agar culture as seen floating about in the microscopic preparation is represented in Fig. 2, C.

Fate and Function of the Detached Hyphal Cells.

Since these large detached cells appear so early in the development of a culture and in such large numbers, it does not seem probable that they represent merely a stage in the degeneration or breaking down of the mycelium. Apparently they have some rôle in the life history of the organism. In order to determine whether they are capable of further development, a culture was thoroughly shaken in water and the detached cells floated out on sterile agar plates as described previously for germination of

the spores. Within twenty-four hours slender tubes of about half the diameter of the original cells could be observed growing out from them. These tubes originate from one or from both ends of the cell, quickly become septate and branched, and within three days each is the center of a white mycelium which can be seen with the naked eye. The centrifugal emptying of the cells, the branching, and all other characters are the same as those of the growths from the chlamydospores. Practically 100 per cent germinated. No conidia could be found on them at any stage. The development of these cells is represented by Fig. 2, D.

Taken in connection with the fact that no true conidia have appeared in any of the cultures, the conclusion seems warranted that these cells detached by division of the vegetative hyphæ are analogous to and serve the same purpose as the sporidia (conidia) of other smut fungi in propagation and dissemination. In fact, almost any cell of the mycelium which retains its protoplasm is a potential spore, and may serve all the functions of the same. Since the cells are so easily detached and germinate so quickly and universally, their importance in the distribution of the disease can hardly be overestimated.

Life in the Soil.

There are at least two ways in which the organism may pass from the host into the soil; (1) when the spores are mature and the sorus is exposed by rupture of the enclosing host tissue, the spores fall out or are blown or shaken out by various agencies and fall to the ground; (2) as previously described, mycelium from any buried lesion may grow from the disintegrating tissues directly into the surrounding soil. It has also been indicated in cultures on soil extract media that the soil contains all the elements necessary to induce germination of the spores and to nourish the mycelium into further growth. In order to study further this period of development of the organism, pure cultures on soil were made by inoculating Ehrlenmeyer flasks of sterilized soil, some by placing a small portion of diseased cotyledon on the center of the surface of the soil, others by placing bits of mycelium from agar tubes in the same position. Within a few days the mycelium could be seen plainly with the naked eye passing from both into the soil and spreading over its surface. After four weeks it was isolated from all points of the soil surface. After more than a year it could still be isolated in pure culture. Microscopic examination of mycelium from the soil showed the same characters that are previously described for cultures and the same detached cells.

Summary of the Saprophytic Stage in the Natural Life History.

From all that has preceded concerning this stage we may draw some conclusions.

1. The fungus lives naturally in the soil, especially where there is an abundance of organic material.

2. It derives sufficient nutrient materials from the soil to grow and spread extensively during this stage.

3. It enters the soil either as spores or as mycelium from the buried parts of diseased onions.

4. No typical conidia (sporidia) are produced but it can be widely disseminated by the detached mycelial cells which may be carried about by water, wind, rain, tools, animals, workmen, etc.

5. It probably lives in the soil in this state for years without the presence of onions.

6. As will be shown later, infection may take place directly from this mycelium, and the presence of speres is not necessary.

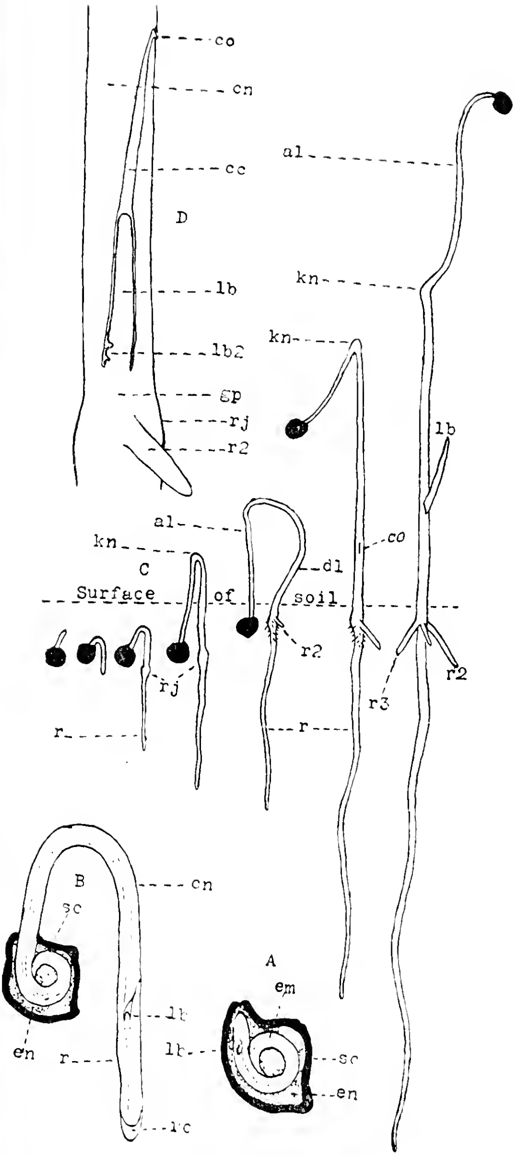
7. The number of years which must elapse before onions can be grown safely on an infested piece of land is not necessarily decided by the longevity of the chlamydospores, but in all probability by the length of time during which the mycelium can continue to live and develop saprophytically without having to pass again through a parasitic stage.

IV. Infection.

Very little has been published concerning infection except the bare fact that it occurs at an early period in the growth of the plant. Concerning the method and point of entrance, character of inoculum, etc., nothing has been previously ascertained.

Development of the Onion Seedling.

In order to understand the description of infection given below it is necessary that the reader should know something of the stages through which an onion seedling passes during the process of germination. The resting seed consists of a hard, black outer seed coat, a nutritive endosperm, and an embryo. The embryo is coiled like a snail within the endosperm (Fig. 3, A). The larger part of the coil represents the cotyledon; only a short portion of the free end is the radicle. In the lower part of the cotyledon, just above where it joins the radicle, there is, even at this early stage, a small cavity. A minute bud, *lb*, arises from the base of and projects into the cavity. This bud is the primordium of the first leaf, and the cavity in this and later stages is called the cotyledonary cavity, *cc*. Several layers of elongated cells throughout the length of the center of the embryo indicate the position which the fibrovascular bundle of the seedling will occupy. Germination begins with rapid elongation of the embryo, the radicle and lower part of the cotyledon being thus pushed through the micropyle, a small opening in the seed coat. This elongation is effected both by longitudinal stretching of the cells of the embryo and by cell division. Food and water for this activity are absorbed by the upper end of the cotyledon which remains attached in the endosperm. On the third day after planting, the projecting radicle is about 3 to 4 mm. long. The root usually points upward as it emerges, but geotropism soon causes it to turn downward and the cotyledon describes a sharp curve as indicated in Fig. 3, B and C. It will be noticed that the tip of the leaf bud now



A. Section through a resting seed.
B. Longisection of a seedling four days after planting.
C. Successive stages in the development from the third day to the twenty-fifth day.
D. Diagrammatic longisection through the growing zone at the end of two weeks. Symbols for parts are the same in all:

sc, seed coat.
en, endosperm.
em, embryo.
lb, leaf bud or primordium of first leaf.
rc, root cap.
r, radicle or first root.
cn, cotyledon.
rj, root joint.
kn, knee.
al, ascending leg.
dl, descending leg.
co, exterior opening of cotyledonary cavity.
r2 and *r3*, first and second secondary roots.
cc, cotyledonary cavity.
gp, growing zone, region of origin of all leaves and roots.
lb2, primordium of second leaf.

FIG. 3. — Development of an onion seedling.

points upward. At this early date the point of division between radicle and cotyledon is indicated by a slight swelling, the root joint, *rj*. As all the parts continue to elongate rapidly the curve in the cotyledon becomes a sharp knee, *kn*, the part between the knee and seed is the ascending leg, *al*, while that between the knee and the root joint is the descending leg, *dl*. The primary root grows down very rapidly and is soon several times as long as the cotyledon. From about the fifth day it will be noted that the descending leg elongates more rapidly than the ascending leg. The first part to appear above ground (seventh to tenth day) is the tip of the knee, and each part becomes green as soon as it has reached the light. The seed may still remain in the ground for a week or more after the knee has appeared, but since it is firmly attached, and since the descending leg continues to elongate more rapidly than the ascending leg, the seed is finally carried into the air (Fig. 3, C). The knee then has a tendency to straighten out, but its position is indicated as long as the cotyledon lives by a sharp kink. On about the ninth or tenth day the first secondary root, *r2*, may be seen pushing out from the swollen root joint, and this is followed later by others in rapid succession, *r3*. Meanwhile the first leaf bud has been elongating rapidly. The cotyledonary cavity elongates also in proportion (Fig. 3, D). It should not be understood that this cavity is absolutely included, without any opening to the outside; on the contrary, its upper narrowed apex communicates with the outside air through a small longitudinal slit in the side of the cotyledon (CO in Fig. 3, C and D). As the leaf bud pushes its way upward the sides of the cavity are distended, and finally from about the seventeenth to twenty-fifth day the tip passes through the slit and appears on the outside as the first leaf (*lb* in Fig. 3, C). But before this time the primordium of the second leaf, *lb2*, has appeared in a depression at the base of the first, and successive leaves follow rapidly, each starting from the base of the next preceding at a very early stage. The successive secondary roots also start from the same region. This very active meristematic region, the growing point, *gp*, is very restricted, and remains stationary in the onion until after the bulb is formed. The limited size and stationary position of the growing point from which all new organs, roots or leaves, originate are characters of prime importance in the spread of the smut fungus within the host plant.

Period of Susceptibility.

It is a well-known fact that onions are susceptible only in the seedling stage, and are immune after a certain stage of maturity is reached. But we have no exact knowledge of the duration of this period of susceptibility, the exact stage or time at which infection first occurs, or the stage or time at which it ceases. The establishment of two points is thus necessary: (1) the first day on which infection takes place, and (2) the last day during which the plant can be infected. The latter of these two points was established by the following experiment. Seed was planted in a flat of sterilized soil. Beginning with the third day, when the radicle on the

most advanced was less than $\frac{1}{2}$ cm. long, and had not even started in many of them, 50 plants were transferred each day to soil which was badly infested and which could be depended on to produce almost 100 per cent of infection. Notes were made on the stage of development of the seedlings each day, and a careful record was kept of all the plants which became smutted. After six weeks, when the plants were mostly in the fourth leaf (after which infection never starts), all of them were pulled, and the following table compiled to show the complete results of the experiment: —

Days between Planting and Transplanting.	Percentage of Infection.
3	100
4	100
5	95
6	100
7	100
8	98
10	87
11	87
12	70
13	59
14	15
17	6
18	–
19	–
Check (left in original sterile sand)	–

The following conclusion may be drawn from this experiment: Under greenhouse conditions the greater part of the infection occurs within two weeks after planting, and the plants are no longer susceptible after the seventeenth day. Since it seems probable that the period of susceptibility is not limited by the number of days during which the seeds have been in the soil, but by the length of time required for the seedling to pass through certain stages of development, we may express this first conclusion by stating that susceptibility begins to diminish from the time that the knees emerge from the ground, and that little if any infection occurs after the first leaf has emerged from the side of the cotyledon. In a large number of experiments in the greenhouse at all times of the year it has been found that the knees begin to appear above ground in seven to twelve days. In one experiment, where the house was very cool, it required over two weeks, and in this case the percentage of infection was 100, and the individual plants were more thoroughly smutted than in any other experiment tried. Since, then, the period of susceptibility might be increased

by the length of time required for the seedlings to reach a certain stage, it is well to inquire how the rate of growth in the greenhouse compares with that in the field. During the spring of 1920, when the spring was late and cold, onions in the field did not come up for over two weeks in most cases, but growers have frequently told the writer that they have had fields which came up within eight days. Apparently weather and soil conditions may materially affect the length of this period. Depth of planting might also influence slightly the length of the period and also the chances of infection. The experiment reported above, however, gives us no information as to the date when infection begins, but only indicates that it ends with about the seventeenth day.

In order to determine the stage at which the earliest infection starts, — and at the same time to work out other points in the early life history, — another bed of onions was started in the greenhouse with soil known to give 100 per cent of smut infection. Beginning with the third day, a certain number of plants was dug up each day, fixed in Flemming's weaker solution, run up into paraffin, sectioned, mounted serially and stained with triple stain. No mycelium was found in the tissues of those which were fixed on the third and fourth days. The first infection was found in a plant which was dug up on the fifth day after planting, and was apparently a very young infection because it had at no point penetrated more than to the fifth layer of cells below the epidermis, and at its furthest point was not more than 150μ from the point of infection. Fifteen other plants dug at the same time were carefully searched under high power through every section of 92 slides, but no other trace of mycelium was found. It is probable, therefore, that only rarely, if ever, has the mycelium entered the tissues of the plant on the fifth day after planting (second day after germination has started). Since cultural experiments with the smut fungus have shown it to be of very slow growth, at least in the saprophytic condition, it seems hardly possible that it could have succeeded in entering the tissues before the second day after germination of the seed starts.

It may be concluded from everything which has been learned up to the present in regard to the period of susceptibility that *infection may take place at any time between about the second day after the seed starts to germinate until the seedling is in the first leaf* (a period of about twelve days in the greenhouse).

Point of Infection.

In the study of the plants fixed and stained as mentioned above, many very young infections were found where it was possible to determine the point of entrance for the mycelium. Infections were found at the knee above, at the root joint below, and at various points between, also at least one through the interior wall of the cotyledonary cavity. The conclusion is, therefore, that all points of the epidermis at least between the root joint and the knee are susceptible to penetration by the smut tubes. Infection was never found taking place in the roots proper or between the

seed and knee. From observation of mature sori, however, it seems probable that infection sometimes occurs above the knee. Mycelium in various quantities has been found in the cotyledonary cavity of many plants, even in the youngest stages, and by tracing it to the opening of this cavity it can be seen that it comes in from the outside through the natural opening, but in most cases it has been impossible to trace a direct connection between this mycelium and any hyphæ inside the tissues between the cells. This mycelium has the size and all the other distinctive characters of smut mycelium, but it is not possible to prove that it is such. It was thought at first that this was the usual infection court, but after it was demonstrated beyond any question that in a large number of cases young infections could have no connection whatever with this cavity, the conclusion was reached that only a small part of the infection could be accounted for in this way. It is still doubtful whether the mycelium which was found in the cavity was always that of Urocystis, or whether it may have been that of another soil fungus.

It is probable that *all infection takes place through the cotyledon*. A case was never noted where the leaf became smutted while the cotyledon remained healthy. More careful experiments on this point, however, might show that the leaf does sometimes become infected first. It is probable that all infection takes place beneath the surface of the ground.

Character of the Inoculum.

In all literature on onion smut it has been assumed that the spores of the organism must be present in close proximity to the seedling in order that infection may occur. The possibility that the mycelium might be present and growing saprophytically and indefinitely in the soil, and might infect without the immediate presence of spores, has been left out of consideration. In order to determine the ability of saprophytic mycelium to produce infection, onion seeds were germinated beneath the surface of agar cultures in test tubes in such a way that the developing seedling as it elongated must pass through the mat of mycelium. Over 50 per cent of the seedlings became infected, although no smut spores could have been present. In the stained sections which were studied, in a few cases mycelium was found outside the walls of the epidermal cells where infection has occurred. Only in one case were spores found in these sections, and at that time there was no infection beneath them. It is probable, however, that spores would usually be removed by the washing process, and this could hardly be adduced as conclusive evidence against the necessity of spores for infection. It is probable that *either spores or saprophytic mycelium in the soil can serve as the inoculum.*

Method of Entrance.

The infecting hypha enters the epidermal cell by boring directly through the outer wall. Since in the younger infections the stomates are not yet open, and mechanical wounds have not been found, there is no other route

by which it could make its way into the interior tissues of the plant. A stage of infection has not yet been found so young that the tube has just entered the epidermal cell and has not progressed further.

Passage through the Epidermal Cells.

In the youngest infections observed, the mycelium had already grown through the epidermal cells, and its tips could be found in the intercellular spaces at a depth of two or more layers below. In some cases a piece of the infecting hypha still remained on the exterior of the cuticle, but was always devoid of contents and consisted only of somewhat crumpled walls

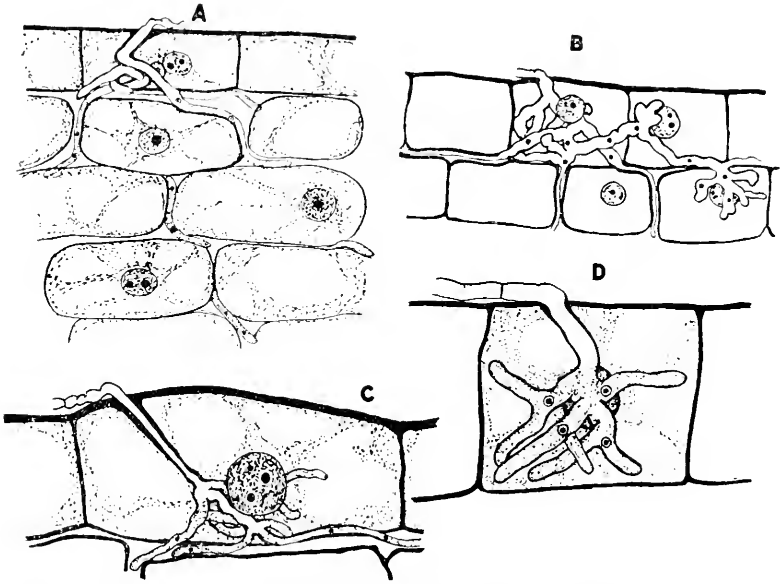


FIG. 4. — Infection through the epidermal cells; A, B, C from outside the cotyledon, D from the cotyledonary cavity.

(Fig. 4). A broad clear canal passes inward from the outer wall usually directed toward the cell nucleus. The wall of the canal appears to be continuous with the cell wall as if merely an inward extension of the same. Commonly it is much thicker at the point of entrance, and resembles a slender funnel or trumpet in shape. It was not found possible to determine whether part of the wall of the canal is an inward growing sheath of the same substance as the cell wall, or whether it is merely a thickened wall of the hypha. In all the cases observed, the canal was empty at the point of entrance. The host nucleus appears to exert an attractive influence. When the tube has reached the depth of the nucleus, it branches to form a tangle of stout, swollen, gnarled, hyphæ which may be confined to the region immediately about the nucleus, or may reach to all parts of the lumen of the host cell (Fig. 4). They may be entirely devoid of con-

tents or — depending on the stage at which one finds them — may contain protoplasm and bright red nuclei scattered singly or in pairs. The hyphal tangle may be confined to the lower (inner) part of the cell, and is always more dense there (Fig. 4, C). Its windings are difficult to follow. These intracellular windings stain red with the triple stain. There is a marked contrast between the large, swollen winding intracellular hyphæ and the trim, slender, straight intercellular hyphæ between the cells below, which stain violet and are of only about one-half the diameter of the former. Usually the tangle is confined to one epidermal cell, but sometimes the adjacent cells may be invaded (Fig. 4, B). The attacked epidermal cells do not collapse, and, in fact, appear practically normal. Hyphæ pass down from the tangle through the inner wall of the epidermis into the intercellular spaces immediately beneath.

Multiple Infection.

The same plant may suffer from a number of infections. In one plant fixed eight days after planting, the mycelium was found passing in through the epidermis at six points on a piece of the cotyledon less than a centimeter in length. In young stages it is not difficult to trace each mycelium to its limits between the cells, and in this case no one of the six had come into contact with another. It is not unusual to find seedlings which show five or six sori on the same cotyledon. Microscopic examination indicates that these are not the results of a single infection, but that for each sorus there is at least one infection thread which penetrated the epidermis from the outside. This statement, however, does not apply to the sori which appear later on the true leaves.

V. Incubation Period.

The incubation period is the time which elapses between infection and the first externally visible symptom of disease. Since the first external symptoms appear at approximately the same time that the spores are forming, we may say that the incubation period is that segment of the life cycle between infection and sporogenesis. In the greenhouse the first symptom, a slight curving and thickening of the cotyledon, has been observed here on the tenth day. Since, as previously stated, infection may take place as early as the fifth day, we may consider that this period occupies a space of about five days under favorable conditions in the greenhouse. It may be longer outside, but, at most, is a comparatively short period. During this period the parasite grows rapidly, spreads inside the host and prepares to form spores.

Young Hyphæ in the Intercellular Spaces.

After passing through the epidermis the hyphæ are intercellular during the remainder of their development. Just below the inner epidermal wall they spread in all directions. They are long, slender, and, as they pass

along the longitudinal walls, appear very straight. They appear to progress somewhat more rapidly up and down the cotyledon than in a radial direction inward. In the young stages they do not occur in strands or bunches between the cells, but one finds them running singly (Figs. 4, A and 5, D). They do not appear to be going toward any definite point, but are spreading more or less in all directions. They are undoubtedly septate, but the septa in the very young hyphæ are difficult to distinguish. The protoplasm passes to the growing tips, and leaves empty the cells behind it. These tip cells stain deep violet with the triple stain, while those cells behind them take less and less stain until only the thin line of the walls can be seen. The nuclei stain bright red and are very prominent, especially back of the deep violet tip cells. These nuclei may occur singly or in pairs distributed along the hyphæ. At this stage it is not always possible to tell whether the two nuclei of a pair are in the same or different cells, but by a comparison with what is found in hyphæ somewhat older, it is probable that here also the cells may be either uninucleate or binucleate. The contents of the hyphal cells appear homogeneous, and at this stage there are no vacuoles or oil drops. The hyphæ seem to be mostly tightly pressed against the walls of the cells, but at places can be seen passing from the wall of one cell to that of another across the open spaces. The cells are long and the branching not close as in the later stages. The branches always arise monopodially from just below the septum, as previously described.

Haustoria.

These absorbing organs are not numerous, but are not uncommon. In some infections none could be found, while in others they are fairly common. They are of various sizes and of very irregular shape (Fig. 5, A–E). They are not much different from the haustoria of other smuts as described by various writers. They are always very much branched, but the branches may be reduced to mere knobs or short stubs which are frequently bifid at the apices (Fig. 5, A). In the larger haustoria, however, the branches are longer and more lax, and may go to all parts of the cell (Fig. 5, B and C). The branches of these larger haustoria are usually — but not always — imbedded in the protoplasm about the nucleus. In some cases they seem to be tightly gripping the nucleus, and the latter appears indented by the pressure. Their shape and size can be best understood by reference to the figures. In many of them an appressorium-like expansion of the hypha can be seen flattened against the outside of the cell wall, and from the lower side of this expansion a narrow neck passes through the wall (Fig. 5, A, E). It is not certain, however, that this appressorium is always present. In the larger haustoria, red nuclei can be distinguished in varying numbers, but in smaller ones, and, in fact, in many of the larger ones, no nuclei can be seen. In some, the position of the nucleus in the stalk of the haustorium is evident (Fig. 5, C) but

apparently there is no uniformity either in the position or number of nuclei. The haustoria usually stain yellowish brown with the orange G of the triple stain.

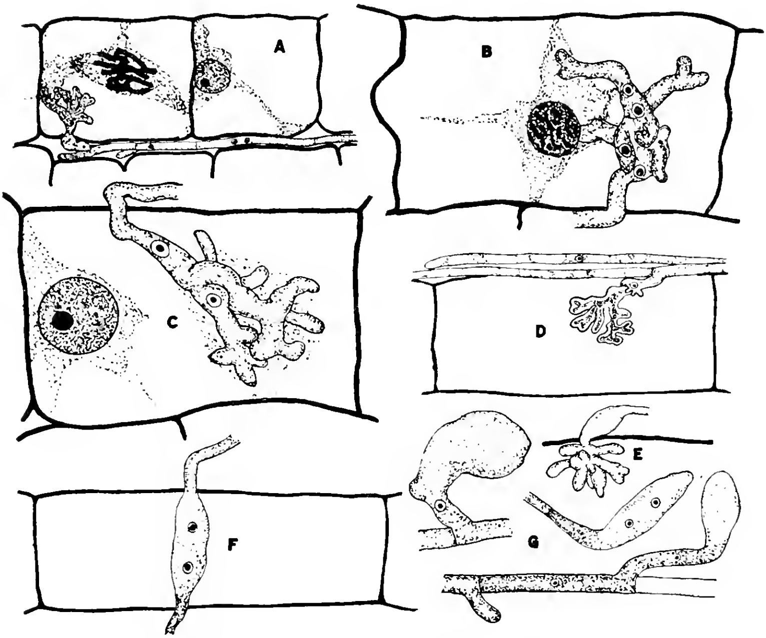


FIG. 5. — Haustoria (A–E) and absorptive hyphal expansions (F, G).

Absorptive Hyphal Expansions.

Frequently during the incubation period one finds the tips, especially of short lateral branches, flattened out like spatulas against the cells of the host. In some sections, just before sporogenesis, these structures may be found in great numbers. Usually they are terminal (Fig. 5, G), but not infrequently they may be found intercalary within the ordinary course of a hypha which, beyond the expansion, continues in its normal size and shape (Fig. 5, F). They resemble the appressoria previously mentioned as the bases from which the haustoria arise, but their number is out of all proportion to the number of haustoria which one finds in the same sections. No description of these organs has been given elsewhere, and their function or meaning is not clear. One can only conjecture that their purpose is to present a broad absorbing surface for securing more nourishment from the host cells. It seems doubtful whether haustoria are really necessary in this connection, because many infections have been studied under the microscope in which no haustoria could be found.

Progressive Infection of New Leaves.

It is a common belief, supported by statements in the literature of the disease, that when a seedling once becomes infected it never recovers. Such, however, is not the case. The writer has watched the development of many seedlings which had infected cotyledons, but which developed into healthy onions. On the other hand, he has not seen an onion, in which the *first leaf* was affected, which produced a healthy bulb. Usually each successive leaf will show smut sori, and they are not always in any apparent relation to the sori on older leaves. As previously stated, all infections come through the cotyledon, but the fate of the plant depends on the point in the cotyledon at which infection takes place. If it occurs only high up toward the knee, or above it, there is a pretty good chance that the host tissue will have become mature or dead and no longer suitable for spread of the mycelium before the latter has reached the growing zone, and the bulb will develop normally. But if infection occurs at or very near the root joint, the mycelium quickly penetrates tc the growing zone from which all future leaves arise. This meristematic tissue furnishes the ideal condition for continuous vegetation of the pathogene, and as each new leaf pushes out from this restricted stationary zone it contains filaments from which the new sori of the successive leaves develop. When the parasite is once established in this growing point, the host seems never to be able to shake off its grip, and is doomed. It is not quite so clear why the mycelium does not enter the tissues of the developing roots in the same way, but the writer has never been able to find it in these organs.

VI. Sporogenesis.

The approach of spore formation is first indicated by massing of the mycelium between the cells. Up to this time only long straight slender hyphæ are found spreading singly, or at most not more than two or three together, between the cells. The period during which the pathogene appears to be spreading as widely and rapidly as possible between the cells has just been described as the incubation stage. The distributive hyphæ now begin to branch profusely, and the branches are not straight and parallel to the main hyphæ, but become twisted and interwoven into dense tangles which push the cells apart and increase the area of intercellular spaces within which the spores are to be formed. The hyphæ now become highly vacuolated, and the protoplasm between the colorless vacuoles stains densely blue with the triple stain, while the old cells from which the protoplasm has passed take the orange stain. The beaded appearance of the alternating vacuoles and densely staining cytoplasm is the surest indication of approaching sporogenesis.

These spore nests or sori always occur between the cells of the mesophyll anywhere between the epidermis and the bundles, but have not been found inside the bundles. They are extended in the direction of the length of the leaf or cotyledon.

Observation of the exact course of events in the formation of a spore is rendered difficult by the denseness of the mass of developing spores, and by the fact that in the young stages all the developing parts stain so deeply on account of their very active protoplasm that the nuclei and septa can hardly be made out. In all cases which have been observed, the spore begins as a lateral or terminal branch which curves back on itself in the form of a crozier (Fig. 6, A–I). These hook-like croziers may be seen in enormous numbers in the mycelial tangle at the initiation of sporo-

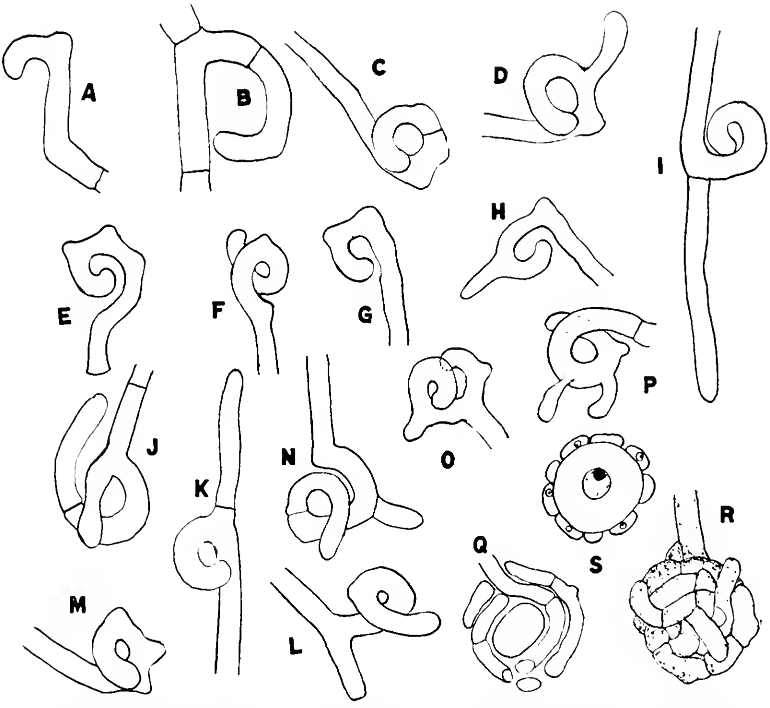


Fig. 6. — Stages of sporogenesis. A–P, development of the crozier and origin of the enveloping hyphæ; Q, section through young spore which is shown in surface view at R; S, section through mature spore.

genesis. Even after the spores at the center of a sorus are fully formed, one may still find various stages of development extending as far back as the crozier, as he passes from the center toward the periphery of the tangle. The croziers remind one of those from which the asci of the Ascomycetes are developed. They stain very deeply, and apparently the protoplasm from the other cells of the hyphæ passes into them. The various shapes which they may assume are best understood by consulting Fig. 6. By growth from the apex of the crozier a complete circle is soon formed and then a spiral if further terminal elongation occurs (Fig. 6, F, L, N, P). At about this time the crozier or spiral begins to appear angular and

irregular (Fig. 6, M), due to protuberances which mark the origin of short lateral outgrowths which soon curve inward along the surface of the developing ball (Fig. 6, P). The whole structure becomes so complicated at this time that it is not always possible to make certain of the exact course of events. The surface view now shows a dense ball of interwoven hyphæ (Fig. 6, R). A cross section (Fig. 6, Q) shows that at the center there is a larger cell which represents what will later be the fertile cell of the spore. This cell appears to be the enlarged terminal cell of the crozier, though it is not certain that this is always its origin. Also it is not entirely certain that all the branches which form the outside of the tangled mass arise directly from the surface of the crozier. In some cases one gets the impression that other hyphæ may be involved, or that branches arise from below the crozier on the same hypha. The transformation from the stage represented in Fig. 6, Q, R, to the mature spore is very rapid. The central cell enlarges while the cells of the surrounding hyphæ become pressed tightly against and united with it. The union between the central cell and the cells of the enclosing hyphæ appears to be stronger than that between the cells of a single hypha of the latter; at any rate, the hyphæ now break up and their elements no longer appear as cells of individual hyphæ, but as scattered conical cells whose flattened bases are firmly attached to the surface of the central cell (Fig. 6, I). This involves a decided change in shape as well as orientation. Nothing has been seen in this process which could be called a gelatinization of cells, such as has been described so often as occurring during sporogenesis in the Ustilaginales.

Approximately at the center of the fertile cell of each fully developed spore there is a nucleus which stains very prominently at this stage of development (Fig. 6, S). In thousands of beautifully stained spores examined by the writer, more than a single nucleus has never been found. It is 3 to 4μ in diameter, with a prominent very red single nucleolus of about .6μ diameter, usually in contact with the nuclear membrane. The membrane is very plain, but the nuclear content, with the exception of the nucleolus, appears only as a few fine granules of cromatin aggregated about the nucleolus or around the inside of the membrane. In each accessory cell there is a single small nucleus of about the diameter of the nucleolus of the fertile cell. In *Urocystis Violae*, Dangeard reported that there were no nuclei in the accessory cells. With the staining methods used it was impossible to determine whether the nucleus of the mature spore results from the fusion of two nuclei. In *U. Anemones* (Pers.) Wint., Lutman found that the cells of the vegetative hyphæ are binucleate and remain so until after the formation of the spore ball, and that the large nucleus of the mature fertile cell results from fusion of the two nuclei. Such might well be the case here, because in the vegetative hyphæ, as previously mentioned, about half of the cells are binucleate, while in the mature spores all cells are uninucleate.

With the full development of the sorus, the host tissue above it dries out and may split open and permit the escape of the dry powdery mass of

spores. In the larger leaves the opening of the sorus may first occur on the interior of the hollow leaves. Under moist conditions other fungi, such as Fusarium, may cause the tissue to decay more rapidly, and thus aid in the liberation of the spores.

The first outward indication of disease in a young seedling is a slight curvature of the cotyledon accompanied by some enlargement of the affected part. In the greenhouse I have found these symptoms as early as the tenth day after planting. Within another day or two, when an affected seedling is held so that the light will shine through it, the lesions may be located by the darker appearance. As soon as the spores are mature the dark sorus can be seen through the tissue without holding it up to the light. The length of time which elapses before it splits open and permits the escape of spores varies greatly with the weather, age of leaf, and other factors.

VII. Summary.

1. Spores as soon as mature germinate in the laboratory in onion decoction, sugar solutions, onion decoction agar, soil agar, manure decoction agar and various agars containing sugar.

2. They do not germinate in tap water, distilled water or soil water.

3. The presence of the onion or any substance from the onion is not necessary.

4. Freezing does not increase or hasten germination, but when spores are frozen in the ground they are not killed.

5. Free access to air increases the percentage of germination.

6. A period of rest in damp soil increases the percentage of germination, but is not necessary.

7. In the soil the spores do not all germinate at once, but become progressively prepared for germination. They do not wait until a host plant starts to grow near them.

8. Germination begins in three to six days after the spores are brought under favorable conditions.

9. A short hemispherical promycelium is first developed, and from this a whorl of branches grows out.

10. The branches grow as mycelium indefinitely without producing conidia (sporidia). The older cells become devoid of their protoplasm progressively.

11. The germination process is very similar to the same process in other species of Urocystis, being almost identical with that of *Urocystis Anemones*. Of the investigated species of this genus, only *U. Violae* produces sporidia.

12. *Urocystis cepulae* lives and grows as a saprophyte indefinitely in the soil, its growth being favored by manure.

13. It may be grown in pure culture on a wide range of culture media, and shows cultural peculiarities by which it may be distinguished from other fungi.

14. Sugar in the media greatly increases the growth. The same substance probably accounts for its rapid growth in the host.

15. Starch furnishes a very poor source of carbon.

16. Decoctions from soil or manure furnish all the essentials for growth.

17. A small amount of acid checks its growth.

18. Freezing does not kill the mycelium.

19. No sporidia (conidia) have been found by the writer in pure cultures or in soil.

20. The mycelium at an early stage breaks up into short plump cells which have all the functions of sporidia and are probably of great importance in dissemination.

21. The organism gets into the soil either by means of spores when the sorus is broken up, or as mycelium which grows from the lesions when in contact with moist soil.

22. Infection occurs during the time from the second day after the seed germinates until about the time that the first leaf appears on the side of the cotyledon, after which the plant is immune.

23. Infection occurs only through the cotyledon, and any part of its epidermis may serve as the point of infection.

24. The infecting hypha bores directly through the outer wall of the epidermal cell, forms a hyphal gnarl inside the cell, and then passes through the inner wall into the intercellular spaces where it grows during the rest of its development.

25. Many infections may occur on the same cotyledon.

26. The incubation period is less than a week.

27. Large complicated haustoria are formed within the host cells.

28. An infected plant recovers if the fungus fails to reach the growing zone; but if it once becomes established in this zone, the plant never recovers, and most if not all the leaves will contain lesions.

29. At the close of the incubation period the mycelium is in dense masses between the cells, and from this the spores develop in sori.

30. The spore begins as a recurved lateral or terminal branch, forming a crozier, circle or short spiral.

31. Branches arising from the circle (crozier) form a close covering about the terminal (fertile) cell.

32. By adhesion of the cells of the covering hyphæ and rapid expansion of the fertile cell the enclosing hyphæ are separated into the scattered elements which appear as the sterile cells of the mature spore.

33. The fertile cell contains a single, large nucleus, and each sterile cell a single small nucleus. Probably the large nucleus is a result of fusion.

VIII. Literature Cited.

(1) Bary, A. de. Untersuchungen über die Brandpilze. Berlin. 1853.
(2) Bary, A. de. Comp. Morph. and Biol., etc. 1887.
(3) Brefeld, O. Untersuch. a. d. Gesam. Myk. 5.
(4) *Ibid*, Vol. 12.

(5) Duggar, B. M. Physiological Studies with Reference to the Germination of Certain Fungous Spores. Bot. Gaz., 31:38. 1901.
(6) Hallier, E. Phytopathologie. Leipzig. 1868.
(7) Fischer von Waldheim. Contribution to the Biology and History of the Development of the Ustilagineae. Trans. N. Y. Agr. Soc., 1870:280.
(8) Kellerman, W. A., and Swingle, W. T. Loose Smut of Cereals. Ann. Rpt. Kans. Sta., 2:213. 1890.
(9) Kühn, J. Über die Entwicklungsformen des Getreidebrandes, Naturf. Ges. Halle. 1874.
(10) Kühn, J. Krankheiten der Kulturgewachse. Berlin. 1858.
(11) McAlpine, D. Smuts of Australia. Melbourne. 1910.
(12) Norton, J. B. S. A Study of the Kansas Ustilagineae, especially with Regard to their Germination. Trans. St. Louis Acad. Sci., 7:229. 1896.
(13) Osner, G. A. Leaf Smut of Timothy. N. Y. (Cornell) Bul. 281. 1916.
(14) Plowright, C. B. A Monograph of the British Uredineae and Ustilagineae. London. 1889.
(15) Prevost, I. B. Memoire sur la Cause immediate de la Carie oux Charbon des bles. Paris. 1807.
(16) Prilleaux, E. E. Sur la Formation et la Germination des Spores des Urocystis. Bul. Soc. Bot. Fr., 27:204. 1880.
(17) Schmaler, F. Über den Einfluss verschiedener Temperaturen auf die Keimfähigkeit der Stein Brandsporen. Forsch. Geb. Agr. Physic., 3:288. 1880.
(18) Thaxter, R. The Smut of Onions (*Urocystis cepulae*, Frost). Ann. Rpt. Ct. Exp. Sta., 1889:129.
(19) Wolff, R. Beitrage zur Kenntniss der Ustilagineen. Bot. Zeitung, 31:657. 1873.
(20) Woronin, M. Beitrag zur Kenntniss der Ustilagineen. Abh. Senck. Nat. Ges., 12:559. 1882.

BULLETIN No. 205.

DEPARTMENT OF CHEMISTRY.

THE NUTRITIVE VALUE OF CATTLE FEEDS.

3. DRIED APPLE POMACE FOR FARM STOCK.

BY J. B. LINDSEY, C. L. BEALS AND J. G. ARCHIBALD.

INTRODUCTION.

Apple pomace is the residue after the extraction of the juice from apples. This has usually been done by many small cider mills located in the various country towns, but of late years the business of cider and vinegar manufacture has become more centralized in large plants employing the most modern machinery. The large establishments in Massachusetts are those of W. W. Cary & Son, Lyonsville; the E. F. Gerry Company, Lynnfield Centre; F. E. Jewett & Son, Lowell; New England Vinegar Works, Somerville; and the Sterling Cider Company, Sterling. After the extraction of the juice, the pomace has been thrown away or used more or less by farmers in the vicinity of the mills. One large concern reports that much of the pomace is taken by the farmers, well packed in silos, and fed during the winter. More recently, two manufacturers (Sterling Cider Company and W. W. Cary & Son) have dried the pomace, the latter company reducing its water content from 63.5 to less than 10 per cent. The value of this dried pomace for feeding purposes has been the subject of our study, and the results are presented in this bulletin. The material for the work was received from W. W. Cary & Son, whose plant we have visited and inspected on two occasions.

The number of cider apples produced in Massachusetts naturally varies much from year to year and no exact data on the subject are available. Munson of the Massachusetts Department of Agriculture states that the difference between the total crop of apples and the commercial crops for the last five years was as follows: —

	Bushels.				
	1916.	1917.	1918.	1919.	1920.
Total crop,	3,450,000	2,186,000	2,430,000	3,240,000	3,680,000
Commercial crop,	1,551,000	675,000	900,000	1,005,000	1,125,000
Difference,	1,899,000	1,511,000	1,530,000	2,235,000	2,555,000

This difference, according to Munson, represents the apples which were not sold in the larger markets but remained on the farm and were wasted or used for by-product purposes, including cider. W. W. Cary & Son use an average of about 60,000 bushels a year; the New England Vinegar Works used 90,000 bushels obtained in Massachusetts in 1920, but are getting none this year (1921); while the Sterling Cider Company use an average of from 8,000 to 10,000 bushels of Massachusetts apples yearly, most of their supply coming from Maine. It is evident that a very large amount of non-marketable apples goes to waste, but it is believed that as time passes more of them will be saved and utilized.

Composition of Dried Apple Pomace.

Table I. — *Composition of Dried Apple Pomace, with Other Carbohydrate Feeds for Comparison.*

No. of Samples.	Feed.	Water.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.	Total.
6	Dried apple pomace (W. W. Cary & Son).	5.30	1.47	5.57	18.20	65.00	4.46	100.00
6	Apple pomace (local product),[1] .	5.30	3.34	5.57	16.16	64.62	5.01	100.00
38	Dried beet pulp,[2]	9.00	3.00	9.00	18.70	59.60	.70	100.00
193	Corn meal,[3]	12.00	1.30	9.50	2.00	71.50	3.70	100.00

[1] Compilations of analyses. Mass. Agr. Expt. Sta. 1919, p. 11. Reduced to same moisture content for comparison.

[2] *Ibid.*, p. 18.

[3] *Ibid.*, p. 20.

The results of the different analyses showed the product obtained from W. W. Cary & Son to be of quite uniform composition. It is clear that the dried pomace is quite low in protein, containing scarcely 6 per cent, and very high in carbohydrates, approximately 83 per cent, of which some 18 per cent are fiber. The fat indicated by the analyses is more of the nature of waxes and gums than true fat. The ash content of the pomace is comparatively low. The dried pomace compares quite closely in chemical composition with dried beet pulp, except that the latter contains several per cent more protein. It is a carbonaceous feed similar to corn meal, although the latter contains more protein and decidedly less fiber. Although of the same type of composition, the corn meal should be more efficient as a source of energy.

Fuller investigation of the nature of the carbohydrates and protein showed the absence of starch and the presence of considerable amounts of reducing and cane sugars and the hemi-celluloses or pentosans. It was also found that about one-third of the total protein is in the amido form.

A study of the mineral constituents of the dried apple pomace showed that it contains less ash than does beet pulp, and that it is particularly

deficient in lime, in which constituent the beet pulp is relatively rich, but contains a fair amount of phosphoric acid and potash.

In calorific value the dried apple pomace compared very favorably with corn meal, sugar and corn starch. Probably the calorific value of the pomace is enhanced by the presence of nearly 5 per cent of waxy material.

Digestibility of Dried Apple Pomace.

In addition to composition, the rate of digestibility is found to throw considerable light upon the nutritive value of a foodstuff, hence eight trials with four different sheep were made, of which seven trials proved to be satisfactory. Four tests were made with the dry, coarse, or unground, pomace; in two cases the pomace was fed with hay, and in two cases with hay and gluten feed, as the basal ration. Three tests were made with the finely ground pomace in which it was fed with hay and gluten feed. The dry, coarse pomace was the product just as it came from the presses; the fine-ground pomace had been passed through an ordinary grist mill and was almost in the form of a powder.

The results showed that the sheep were able to digest on an average 68.5 per cent of the total dry matter in the apple pomace, the fiber and nitrogen-free extract being quite well utilized, the fat to a much less degree,[1] while the protein was apparently not digested at all. We say *apparently* because this peculiarity of indigestibility of protein is often met with in feeds of quite low protein content, and is due to the excretion of nitrogenous material in the form of digestive juices and intestinal wastes. The probability is that the pomace protein, although small in amount, is fairly well utilized.

The trials were not sufficient in number to indicate positively any difference in digestibility between the coarse and the finely ground pomace, and it is doubtful from a nutritive standpoint whether any advantage would be gained in grinding it fine. Compared with other feeds of a similar type, the pomace is shown to be not quite as digestible as dried beet pulp, and much less so than corn meal.

Table II. — *Digestible Matter in 2,000 Pounds.*

Feed.	Dry Matter.	Protein.	Fiber.	Extract Matter.	Fat.	Total Digestible Matter (Fat × 2.25).	Relative Values on Basis of Digestible Matter (Corn meal =100).
Dried apple pomace,	1,298.0	0	248.8	991.2	32.0	1,312.0	81
Dried beet pulp,	1,365.0	93.6	310.4	989.4	–	1,393.4	87
Corn meal,	1,548.8	127.4	17.6	1,315.6	66.6	1,610.4	100

[1] The fat or other extract is largely in the form of waxy matter and has little nutritive value.

This table shows the dried apple pomace to have almost as much total digestible matter as dried beet pulp, but, as would be expected, considerably less than corn meal. Taking the latter as 100, the pomace has a feeding value of 81 and the beet pulp of 87 per cent. In other words, on the basis of digestibility, if properly fed, one would expect slightly better results from the dried beet pulp and noticeably better results from the corn meal than from the dried pomace.

Net Energy Values.

In place of digestible matter as a measurement of nutritive value, Kellner and also Armsby have adopted the unit of net energy. Net energy means the total energy in the feed minus that excreted in the urine and feces, as well as that lost in heat radiation due to the processes of digestion and assimilation. Armsby expresses it in therms, the therm being the amount of heat required to raise 1,000 kilograms of water 1 degree Centigrade.

Feed.	Net Energy in 100 Pounds (Therms).
Corn meal,	85.17
Dried beet pulp,	75.87
Dried apple pomace,	61.39[1]

[1] Estimated according to Armsby's data for beet pulp and corn meal.

On this basis, with corn meal as 100, beet pulp has a relative value of 89 and apple pomace of 72. Both the figures for digestibility and the net energy values show the apple pomace to be slightly inferior to beet pulp as a source of nutrition.

Dried Apple Pomace for Dairy Cows.

The value of dried apple pomace for milk production was carefully studied during a period extending from Nov. 10, 1920, to May 10, 1921. The material was compared first with dried beet pulp and later with corn meal, on an equal dry-matter basis. The dried pomace was fed moist in both experiments, and was mixed with the grain ration shortly before feeding. It was much relished by the cows. The beet pulp was also moistened.

The experiments were conducted by the usual reversal method, eight cows being used in the first trial and twelve in the second.[1] The animals received the usual care as described in earlier publications of the station. The hay was sampled three times during each half of each experiment by taking forkfuls here and there, running the same through a power cutter and subsampling. The subsamples were placed in glass-stoppered con-

[1] One cow was taken sick halfway through the experiment, and her record is therefore omitted.

tainers and brought at once to the laboratory where moisture determinations were made and composite samples analyzed. The grain was sampled each time a new lot was mixed, and the samples preserved as in the case of the hay. The apple pomace and dried beet pulp were sampled at regular intervals during the experiments. The milk was sampled for five consecutive days three times during each half of each experiment, preserved with formalin, and total solids and fat determined in the usual manner on the composite samples.

The basal ration consisted of a uniform grain mixture plus sufficient hay for the needs of each individual cow. The hay was of only fair quality, some of it being too coarse for good cow hay. With the exception of the corn meal fed in the last experiment, all the concentrates fed were up to the usual standards. The corn meal was unusually low in fat (1.69 per cent), and although bought for meal from whole corn could not have been such, probably having had the germs removed. A definite amount of either apple pomace, beet pulp or corn meal was substituted for a like amount of the basal grain ration, this amount varying with the different individuals in the herd. The basal grain rations fed in the two experiments are shown in the following table: —

Table III. — *Grain Mixtures Fed (Pounds).*

Experiment I. Apple Pomace *v.* Beet Pulp.		Experiment II. Apple Pomace *v.* Corn Meal.	
Bran,	20	Bran,	40
Corn meal,	30	Cottonseed meal,	60
Coconut meal,	30		
Cottonseed meal,	20		

A definite amount of each mixture was given to each animal, — in the first experiment from 6 to 10 pounds daily of I, with from 6 to 7 pounds of either apple pomace or beet pulp; in the second experiment from 5 to 7 pounds daily of II, with from 4 to 5 pounds of either apple pomace or corn meal.

Somewhat less of the basal grain ration was fed to each cow in the second experiment than in the first, and the amount of hay per animal increased, for the reason that it was not considered advisable to feed too large an amount of grain in the corn meal half of the trial.

TABLE IV. — *Average Ration consumed per Cow (Pounds).*

EXPERIMENT I.

Number of Cows.	Character of Ration.	Hay.		Apple Pomace.		Beet Pulp.		Grain Mixture.	
		Total per Cow.	Daily per Cow.	Total per Cow.	Daily per Cow.	Total per Cow.	Daily per Cow.	Total per Cow.	Daily per Cow.
8	Apple pomace, . .	590.63	16.88	231.88	6.63	–	–	284.38	8.13
8	Beet pulp, . .	590.63	16.88	–	–	231.88	6.63	284.38	8.13

EXPERIMENT II.

Number of Cows.	Character of Ration.	Hay.		Apple Pomace.		Corn Meal.		Grain Mixture.	
		Total per Cow.	Daily per Cow.	Total per Cow.	Daily per Cow.	Total per Cow.	Daily per Cow.	Total per Cow.	Daily per Cow.
12	Apple pomace, . .	625.00	19.00	157.50	4.50	–	–	218.75	6.25
12	Corn meal, . .	625.00	19.00	–	–	167.65	4.79[1]	218.75	6.25

[1] As the corn meal contained 9 per cent more moisture than the apple pomace, 17 ounces of the former were fed to each pound of the latter.

TABLE V. — *Estimated Dry Matter and Digestible Nutrients in Average Daily Ration (Pounds).*

EXPERIMENT I.

Character of Ration.	Dry Matter.	Digestible Nutrients.					Nutritive Ratio.
		Protein.	Fiber.	Extract Matter.	Fat.	Total.	
Apple pomace, .	28.49	1.86	4.14	11.64	.61	18.25	1:9.22[1]
Beet pulp, . .	28.26	2.17	4.37	11.57	.50	18.61	1:7.87

EXPERIMENT II.

Apple pomace, .	26.33	2.10	4.33	9.07	.53	16.03	1:6.95[1]
Corn meal, . .	26.16	2.38	3.87	9.94	.53	16.72	1:6.30

[1] Assuming that the protein in apple pomace is 50 per cent digestible, these ratios would be lowered to 1:8.4 and 1:6.4, respectively.

The above figures are based upon analyses and average digestion coefficients. They show that the beet pulp and corn meal rations contained slightly more total digestible nutrients than the corresponding apple pomace ration, and also had narrower nutritive ratios. The former fact is due to the less degree of digestibility of the apple pomace, and the latter fact to its low protein content.

TABLE VI. — *Summary of Yields of Milk and Milk Ingredients (Pounds).*

Experiment.	Character of Ration.	Number of Cows.	Milk produced.	Total Solids.	Total Fat.
I,	Dried apple pomace,	8	7,530.1	973.96	330.19
	Dried beet pulp,		7,775.9	1,020.59	351.54
II,	Dried apple pomace,	11	9,371.8	1,226.52	430.52
	Corn meal,		9,570.4	1,271.73	454.42

TABLE VII. — *Percentage Increase, Beet Pulp or Corn Meal Ration over Apple Pomace Ration.*

Experiment.	Character of Ration.	Milk produced.	Total Solids.	Total Fat.
I,	Dried beet pulp,	3.26	4.79	6.47
II,	Corn meal,	2.12	3.69	5.55

The slightly increased yield produced by the beet pulp over the apple pomace is in no way surprising. It was expected, however, that the corn meal would show a larger increase than did the beet pulp. On the basis of digestibility and net energy estimation it certainly should have proved more effective. If it had been possible to have a larger amount of the total ration composed of the feeds under comparison the results would undoubtedly have been more pronounced.

In Experiment I the cows on both rations showed slight gains in weight. In Experiment II the gain or loss was so insignificant as to be unworthy of consideration.

The general effect of the apple pomace ration was good. At the close of the experiments there was considerable pomace still on hand, and a number of the cows not needed for other work were continued for several months on the same ration as fed in Experiment II. All but one continued in good flesh and gave a satisfactory flow of milk.

How to feed Dried Apple Pomace.

The dried pomace contains very little protein, and if fed in combination with hay, corn silage and corn meal the results are bound to prove unsatisfactory and the feeder will at once conclude that the pomace "dries up the cows." Because it is so ill balanced — that is, so rich in carbohydrates and so lacking in protein — it must be combined with protein feeds in order to secure satisfactory results. It may be fed in two ways, as follows: —

As a Component of the Grain Ration.

I.	Pounds.	II.	Pounds.
Wheat bran or mixed feed,	10	Gluten feed,	30
Cottonseed meal,	50	Cottonseed meal,	30
Dried apple pomace,	40	Dried apple pomace,	40

III.	Pounds.
Corn or corn and cob meal,	10
Cottonseed meal,	50
Dried apple pomace,	40

Feed 1 pound of any of the above mixtures for each 3 pounds of milk produced. It is considered safe to feed at least 4 pounds of the pomace daily in dry condition, providing the cows have frequent access to water.

As a Substitute for Corn Silage.

Seven pounds of kiln dried apple pomace may be fed daily, after being well moistened with water, as a substitute for a bushel of corn silage weighing 30 pounds. It is not advised to feed too large quantities at first, but to begin with 2 or 3 pounds of the dried pomace daily and gradually increase to 7 pounds. It is doubtful if, pound for pound on the same moisture basis, the pomace will prove fully equal in feeding value to well-preserved and well-eared corn silage, but it certainly will approach it. This amount of dried pomace, together with what hay the animal will clean up daily, — 10 to 16 pounds, — may constitute the roughage ration; and in addition the cow should receive from 4 to 10 pounds of a suitable grain mixture, depending upon the ability to profitably utilize it. The following grain mixtures are suggested: —

I.	Pounds.	II.	Pounds.
Cottonseed or linseed meal,	300	Cottonseed or linseed meal,	100
Gluten feed or coconut meal,	300	Corn or corn and cob meal, or hominy feed or ground oats or barley,	100
Corn or corn and cob meal or hominy feed or ground oats or barley,	300	Wheat bran or mixed feed,	100
Wheat bran,	200		
Wheat middlings,	100		

III.	Pounds.	IV.	Pounds.
Gluten feed or coconut meal,	300	Cottonseed meal,	100
Wheat bran or wheat mixed feed,	200	Corn or corn and cob meal,	100
Corn or corn and cob meal or hominy feed or ground oats or barley,	100		

Ration IV is rather less bulky than the other rations, and may be fed mixed more or less with the moistened pomace as a precaution against digestive disturbances.

The Economy of Dried Apple Pomace.

The writer has emphasized for a long time that the farm is primarily the carbohydrate factory upon which maximum amounts of corn and hay should be grown as roughages, supplemented whenever possible with clover, alfalfa and possibly with soy beans. These latter furnish more protein and ash than do the non-legumes, and are favorable to milk production, growth and soil fertility. Purchased feed should be in the form of the protein concentrates; and carbohydrates such as corn, barley, hominy, beet pulp and apple pomace, especially for growth and milk production, should be purchased only when the supply of home-grown feed runs low.

To all intents and purposes, however, apple pomace is a home-grown carbohydrate feed. Through drying, waste of this food resource is prevented. The economy of attempting this conservation depends on its cost. Ultimately the carbohydrate feed produced in this way must be sold at as low a price as is asked for other carbohydrates. Whether this will be possible cannot yet be stated, for the process is still new and the cost factors not fully worked out.

Summary.

Apple pomace is now kiln dried in limited amounts, which insures its preservation and greatly enhances its economic value. It is brownish in color, of a mechanical condition resembling fine shavings, and has a slightly acid taste. Chemical analyses show it to be a strictly carbohydrate feed with a high sugar content and lacking in true starch. It is likewise high in fiber, but quite low in both protein and total ash. Phosphoric acid and potash make up fully 40 per cent of the ash.

Experiments with sheep show it to be fairly well digested, especially with respect to total dry matter, fiber and extract matter. Protein and fat are rather poorly digested, an explanation for this being offered in the text.

For dairy cows, it may be fed to the extent of 4 pounds daily as a component of the grain ration, or 7 pounds daily of the dry material may be well moistened with water and fed as a substitute for a bushel of corn silage.

Experiments herein reported show it to be but slightly inferior to both dried beet pulp and corn meal when fed to dairy cows as a component of the daily ration. No objectionable flavor was noted in the milk, nor was there any bad effect upon the health or condition of the animals.

Fed only with other carbohydrate feeds such as hay, silage and corn. dried apple pomace will prove unsatisfactory. The ration must always be supplemented with rich protein feeds such as cottonseed meal, gluten feed and coconut meal.

The chief use of apple pomace will be as a feed for dairy cows, young stock and sheep. It is of doubtful value for pigs, and as a food for horses it is not recommended.

APPENDIX.

TABLE VIII.—*Nature of Carbohydrates and Protein of Dried Apple Pomace.*

[Dry matter basis.]

	Per Cent.
Pentosans,	16.09
Galactan,	3.32
Reducing sugars,	13.88
Sucrose,	6.93
Starch,	None.

Total nitrogen,	.93=5.80 per cent crude protein.
Albuminoid nitrogen,	.68=4.25 per cent true protein.
Amide nitrogen,	.24

TABLE IX.—*Mineral Constituents of Dried Apple Pomace and Beet Pulp.*

[Dry matter basis.]

	Dried Apple Pomace[1] (Per Cent).	Beet Pulp (Per Cent).
Total ash,	1.607	3.954
Insoluble matter,	.221	.830
Phosphoric acid,	.260	.196
Iron and alumina,	.113	.168
Calcium oxide,	.157	1.007
Magnesium oxide,	.100	.502
Sulfur dioxide,	.034	.465
Potassium oxide,	.506	.301
Sodium oxide,	.037	.140

[1] Analyses made by L. S. Walker of this station.

TABLE X.—*The Calorific Value of Dried Apple Pomace.*

[Dry Matter Basis.]

	Small Calories per Gram.	Large Calories per Gram.
Dried apple pomace,	4,589	2,082
Corn meal[1] (for comparison),	4,430	2,011
Sugar, guaranteed[1] (for comparison),	3,958	1,753
Corn starch[2] (for comparison),	3,692	1,675

[1] United States Department of Agriculture, Farmers' Bulletin No. 346, by H. P. Armsby, p. 13.

[2] Journal of Agricultural Research, Vol. VII, No. 7, p. 305.

TABLE XI. — *Digestion Coefficients for Apple Pomace.*

Sheep.

Series.	Experiment	Animal.	Percentages of Ingredients digested. Dry Matter.	Ash.	Protein.	Fiber.	Extract Matter.	Fat.	Ration Fed.
26,	4	9	63.48	–	0	71.41	73.88	28.35	500 grams hay + 250 grams coarse dry apple pomace.
26,	4	11	68.11	56.25	0	72.93	75.78	40.33	
26,	5	17	71.41	2.53	0	87.08	79.01	43.85	550 grams hay + 150 grams gluten feed + 200 grams coarse dry apple pomace.
26,	5	19	59.45	14.01	0	60.98	71.03	36.10	
Average for the coarse dry or unground pomace,	–	–	65.61	24.26	0	73.10	74.93	37.16	– –
26,	6	9	77.02	94.03	0	80.21	83.87	37.14	500 grams hay + 150 grams gluten feed + 200 grams fine dry apple pomace.
26,	6	11	65.49	53.84	0	58.61	75.45	25.22	
26,[1]	8	19	71.82	107.14	0	52.13	73.39	41.38	550 grams hay + 150 grams gluten feed + 200 grams fine dry apple pomace.
Average for the fine dry or ground pomace,	–	–	71.44	84.67	0	63.65	77.57	34.58	– –
Average of above seven single trials,	–	–	68.53	54.47	0	68.38	76.25	35.87	– –
Average of six previous single trials (wet pomace),[2]	–	–	72.00	49.00	0	65.00	85.00	46.00	– –
Dried beet pulp,	–	–	75.00	26.00	52.00	83.00	83.00	–	– –
Corn meal,	–	–	88.00	–	67.00	44.00	92.00	90.00	– –

[1] Sheep No. 17 did not eat well in this trial and had to be rejected.

[2] Seventeenth annual report, Hatch Experiment Station, Amherst, Mass., p. 86.

TABULATED DATA OF THE EXPERIMENTS WITH DAIRY COWS.

TABLE XII. — *History of the Cows.*

EXPERIMENT I.

Name.	Age.	Breed.	Calved.	Served.	Daily Milk Yield, Beginning (Pounds).	Fat (Per Cent).
Fancy V,	3	Grade Jersey,	Aug. 23, 1920	Jan. 6, 1921	22	4.9
Samantha III,	7	Grade Holstein,	Sept. 18, 1920	Dec. 15, 1920	34	4.6
Samantha IV,	6	Grade Holstein,	Sept. 11, 1920	Nov. 13, 1920	34	4.0
190,	–	Grade Holstein,	Oct. 15, 1920	Jan. 15, 1921	27	3.8
Fancy IV,	6	Grade Jersey,	Aug. 15, 1920	Jan. 6, 1921	18	5.0
46,	8	Grade Holstein,	Sept. 18, 1920	Nov. 10, 1920	41	3.7
Colantha II,	6	Grade Holstein,	Aug. 10, 1920	Nov. 18, 1920	34	4.4
Colantha IV,	3	Grade Holstein,	Oct. 18, 1920	Feb. 7, 1921	25	3.7

Table XII. — *History of the Cows* — Concluded.

Experiment II.

Name.	Age.	Breed.	Calved.	Served.	Daily Milk Yield, Beginning (Pounds).	Fat (Per Cent).
Fancy IV,	7	Grade Jersey,	Aug. 15, 1920	Nov. 17, 1920	16	5.9
46,	8	Grade Holstein,	Sept. 18, 1920	Nov. 10, 1920	35	3.2
Colantha II,	6	Grade Holstein,	Aug. 10, 1920	Nov. 18, 1920	32	4.9
Colantha IV,	3	Grade Holstein,	Oct. 18, 1920	Dec. 11, 1920	24	3.7
Ida II,	8	Jersey,	Nov. 14, 1920	Jan. 6, 1921	24	5.5
Red IV,	7	Grade Jersey,	Dec. 31, 1920	–[1]	32	5.3
Fancy V,	4	Grade Jersey,	Aug. 23, 1920	Jan. 6, 1921	21	6.0
Samantha III,	7	Grade Holstein,	Sept. 18, 1920	Dec. 15, 1920	30	4.9
Samantha IV,	6	Grade Holstein,	Sept. 11, 1920	Nov. 13, 1920	33	4.6
190,	–	Grade Holstein,	Oct. 18, 1920	Jan. 21, 1921	28	3.9
Peggy,	10	Grade Jersey,	Nov. 11, 1920	Dec. 9, 1920	25	5.6
Cecile II,	8	Jersey,	Nov. 30, 1920	–[1]	25	5.1

[1] Not bred.

Table XIII. — *Chemical Analyses of Feeds Used (Per Cent).*

Experiment.	Feed.	Water.	Ash.	Crude Protein.	Fiber.	Extract Matter.	Fat.
I,		9.25-12.75					
	Hay,	11.38	5.17	6.59	29.15	45.78	1.93
	Apple pomace,	5.45	1.48	5.48	17.90	65.26	4.42
	Beet pulp,	8.87	3.96	9.10	18.95	58.41	.69
	Grain mixture,	10.75	4.43	19.45	8.20	52.12	5.04
II,		11.53-16.88					
	Hay,	13.44	5.25	7.22	30.03	42.08	1.98
	Apple pomace,	6.21	1.46	5.49	16.69	65.72	4.44
	Corn meal,[1]	15.54	1.29	8.61	2.01	70.85	1.69
	Grain mixture,	9.44	6.16	27.68	11.52	39.71	5.49

[1] The corn meal was unusually low in fat (1.69%), and although bought for meal from whole corn, could not have been such, probably having had the germs removed.

Table XIV. — *Duration of Experiments.*

Experiment I.

Dates.	Basal Ration+Apple Pomace.	Basal Ration+Dried Beet Pulp.	Weeks fed.
Nov. 22, 1920, to Dec. 26, 1920, inclusive,	Fancy V, Samantha III, Samantha IV, 190,	Fancy IV, 46, Colantha II, Colantha IV,	5
Jan. 6, 1921, to Feb. 9, 1921, inclusive,	Fancy IV, 46, Colantha II, Colantha IV,	Fancy V, Samantha III, Samantha IV, 190,	5

Table XIV. — *Duration of Experiments* — Concluded.

Experiment II.

Dates.	Basal Ration+Apple Pomace.	Basal Ration+Corn Meal.	Weeks fed.
Feb. 20, 1921, to March 26, 1921, inclusive,	Fancy IV, 46, Colantha II, Colantha IV, Ida II, Red IV,	Fancy V, Samantha III[1], Samantha IV, 190, Peggy, Cecile,	5
April 6, 1921, to May 10, 1921, inclusive,	Fancy V, –[1] Samantha IV, 190, Peggy, Cecile,	Fancy IV, 46, Colantha II, Colantha IV, Ida II, Red IV,	5

[1] Samantha III was taken sick halfway through the experiment and had to be discontinued. Her record is therefore omitted for the entire experiment.

Table XV. — *Gain or Loss in Live Weight (Pounds).*

Experiment.	Gain.		Loss.		Net.	
	Apple Pomace.	Beet Pulp.	Apple Pomace.	Beet Pulp.	Apple Pomace.	Beet Pulp.
I,	156	195	3	0	153+	195+

Experiment.	Gain.		Loss.		Net.	
	Apple Pomace.	Corn Meal.	Apple Pomace.	Corn Meal.	Apple Pomace.	Corn Meal.
II,	94	90	73	113	21+	23–

Table XVI. — *Total Yields of Milk and Milk Ingredients.*

Experiment I.

Apple Pomace Ration.

Cows.	Milk produced (Pounds).	Total Solids (Per Cent).	Total Solids (Pounds).	Fat (Per Cent).	Fat (Pounds).
Fancy V,	742.4	14.87	110.39	5.86	43.50
Samantha III,	1,014.6	13.74	139.41	4.94	50.12
Samantha IV,	968.8	12.74	123.43	4.54	43.98
190,	971.8	12.28	119.34	3.84	37.32
Fancy IV,	518.8	15.15	83.14	5.74	31.50
46,	1,279.7	10.93	139.87	3.04	38.90
Colantha II,	1,110.2	13.58	150.77	4.73	52.51
Colantha IV,	893.8	12.04	107.61	3.62	32.36
Totals,	7,530.1	–	973.96	–	330.19
Averages,	–	12.93[1]	–	4.38[1]	–

[1] Average percentage of solids and fat obtained by dividing total pounds of each by total milk yield.

TABLE XVI. — *Total Yields of Milk and Milk Ingredients* — Concluded.

EXPERIMENT I — *Concluded.*

Beet Pulp Ration.

Cows.	Milk produced (Pounds).	Total Solids (Per Cent).	Total Solids (Pounds).	Fat (Per Cent).	Fat (Pounds).
Fancy V,	726.7	15.59	113.29	6.24	45.35
Samantha III,	1,033.1	13.98	144.43	4.99	51.55
Samantha IV,	1,144.0	13.10	149.86	4.70	53.77
190,	1,014.5	12.64	128.23	4.13	41.90
Fancy IV,	610.1	15.15	92.43	5.82	35.51
46,	1,413.4	11.12	157.17	3.17	44.80
Colantha II,	877.8	13.61	119.47	4.81	42.22
Colantha IV,	956.3	12.10	115.71	3.81	36.44
Totals,	7,775.9	-	1,020.59	-	351.54
Averages,	-	13.12[1]	-	4.52[1]	-

EXPERIMENT II.

Apple Pomace Ration.

Cows.	Milk produced (Pounds).	Total Solids (Per Cent).	Total Solids (Pounds).	Fat (Per Cent).	Fat (Pounds).
Fancy IV,	524.6	14.52	76.17	5.33	27.96
46,	1,079.1	11.18	120.64	3.29	35.50
Colantha II,	1,065.8	13.01	138.66	4.44	47.32
Colantha IV,	824.6	11.83	97.55	3.66	30.18
Ida II,	829.3	14.02	116.27	5.12	42.46
Red IV,	1,083.0	13.16	142.52	4.80	51.98
Fancy V,	677.6	14.55	98.59	5.51	37.34
Samantha IV,	987.8	12.80	126.44	4.51	44.55
190,	814.4	12.54	102.13	4.17	33.96
Peggy,	747.9	14.12	105.60	5.45	40.76
Cecile II,	737.7	13.82	101.95	5.22	38.51
Totals,	9,371.8	-	1,226.52	-	430.52
Averages,	-	13.09[1]	-	4.59[1]	-

Corn Meal Ration.

Cows.	Milk produced (Pounds).	Total Solids (Per Cent).	Total Solids (Pounds).	Fat (Per Cent).	Fat (Pounds).
Fancy IV,	547.3	14.91	81.60	5.63	30.81
46,	912.6	12.03	109.79	3.51	32.03
Colantha II,	893.1	12.83	114.58	4.74	42.33
Colantha IV,	839.5	12.12	101.75	3.51	29.47
Ida II,	800.0	14.03	112.24	5.33	42.64
Red IV,	1,022.3	13.69	139.95	5.13	52.44
Fancy V,	728.7	14.78	107.70	5.68	41.39
Samantha IV,	1,166.1	12.77	148.91	4.48	52.24
190,	930.7	12.26	114.10	4.08	37.97
Peggy,	871.5	14.10	122.88	5.60	48.80
Cecile II,	858.6	13.77	118.23	5.16	44.30
Totals,	9,570.4	-	1,271.73	-	454.42
Averages,	-	12.29[1]	-	4.75[1]	-

[1] Average percentage of solids and fat obtained by dividing total pounds of each by total milk yield.

BULLETIN NO. 206.

REPORT OF THE CRANBERRY STATION FOR 1919 AND 1920.

BY H. J. FRANKLIN.

The cranberry industry in southeastern Massachusetts, particularly in Barnstable and Plymouth counties, is the most marked feature of the agriculture of that region. It has given large value to some 14,000 acres of peat and muck soils which previously had little or no value, having made mosquito-breeding swamps into agriculturally productive land. It gives seasonal employment to many hundreds of workers, and it adds from two to three million dollars to the value of the agricultural products of the section annually. The cranberry is the most important export crop of the State.

It is thus apparent that anything which injures the cranberry industry affects not only the sections in which the berries are grown but also the Commonwealth as a whole. Partial crop failures, whatever the cause, result in severe loss, both to the bog owners and operators and to the laborers who are accustomed to secure a part of their livelihood by work on the bogs. Reduction of the crop lessens the ability of the community to meet its taxes; it also decreases the purchasing power of the section and so affects other industries. It was to develop methods of avoiding such partial crop failures that the State in 1910 established the Cranberry Station of the Experiment Station.

For ten years the Cranberry Station has been in operation. It has given major attention to the study of the insects which injuriously affect the cranberry crop. It has also investigated the problems of plant disease control, bog fertilization, berry storage, frost protection, cranberry varieties, and even the possibilities of the blueberry as a companion crop to cranberries. In addition, the Cranberry Station has served as a center for growers' meetings, and the services of the specialist in charge in an advisory capacity have been widely sought by the growers. The following report is the eighth of the Cranberry Station, and is a discussion of the more important results of the work of 1919 and 1920.

Field Meetings.

In early June, 1920, five field meetings were held (in Rochester, Carver, Plymouth, Wareham and Sandwich) with cranberry growers to demonstrate the use of the insect net in discovering and gauging certain insect infestations in their early stages. These meetings were planned as a special effort in the control of the gypsy moth, but the other open-feeding caterpillars often harmful to bogs, such as spanworms and false army worms, were also discussed. A supply of nets had been prepared and sixty were sold to growers.

Frost Predictions.

In both 1919 and 1920 much progress was made in perfecting methods of frost predicting. Most of the results of this study and of the frost investigations of previous years are given in a paper lately published.[1] In 1920 arrangements were made with the New England Telephone and Telegraph Company for distributing frost predictions to be sent out by the station in the early afternoon and early evening. This service began in the fall.

Study of Cranberry Varieties.

The study of the characteristics of the Cape cranberry varieties was continued, special attention being given to seed counts. Small plantings of the Pride and Wales Henry varieties were made at the station in the spring of 1920.

Additions to Station Equipment.

In 1919 a lean-to shed, 41 by 20 feet, with a concrete floor, corrugated iron sides, and board and paper roof, was added to the station building. In one end of this, a part 11½ by 20 feet was made into a garage, the larger room being for box and barrel storage. This addition had long been needed, for when the bog produced a large crop the building was too crowded for storage tests.

A screening belt and a Ford runabout truck also were added to the station equipment in 1919. The latter, presented by the Cape Cod Cranberry Growers' Association, was especially helpful, making it possible to visit bogs in distant towns more freely. This extension of the field of operations not only made the station more serviceable to the growers, but also yielded valuable results in the way of new observations.

Yields in 1919 and 1920.

The station bog yielded scantily in 1919 for reasons given below, only about 80 barrels of berries being sold, and this fruit of poor quality. On this account, keeping tests were mostly omitted that year. In 1920 the bog

[1] Monthly Weather Review Supplement No. 16: 20–30, 1920.

produced 909 barrels of unusually sound berries which sold for about $7,300.

The spring and early summer of 1920 on the Cape were wet and backward. Because of the rains, there were a few hundred acres from which it was impossible to remove the winter water early enough to grow a crop, the importance of adequate drainage thus being emphasized again.

In 1920 most of the Cape bogs bloomed very heavily and so aroused the anticipation of a record crop, but there was a marked and widespread failure to set fruit, and the total Cape yield was only about 277,000 barrels. The weather and blossom conditions and the fruiting failure paralleled those of 1916,[1] except that thin vines were not relatively more fruitful.

Fungous Diseases.

The "Rosebloom" Disease.

As the "rosebloom" disease (*Exobasidium oxycocci*) had greatly reduced the crop of Howes and McFarlin berries on the station bog for three successive years, treatment by flooding was tried in 1919. The winter flood was let off March 23, and the shoots enlarged by the disease became partly grown and abundant by May 25 when the first reflooding was done. The water was held sixty hours, the weather being mostly clear. The diseased shoots collapsed and dried up within a day after the flood was let off. More such shoots grew later and were killed by the mid-June flowage mentioned below. Little evidence of the disease appeared on the bog the rest of the season, and comparatively few of the enlarged shoots grew in 1920, the treatment thus seeming to have been largely successful. The early destruction of the diseased growths probably reduced the spore production of the fungus greatly, and thus lessened the infection of the new axillary buds.

Wisconsin False Blossom.

False blossom (the Wisconsin disease) has previously been reported[2] as found on five Cape bogs, the infestation being due to planting Wisconsin vines in every case. All these infestations have been wiped out by destroying the infected vines. In the fall of 1919 six heretofore unnoticed infestations were found by Dr. Stevens of the Bureau of Plant Industry and the writer on Holliston[3] vines in Pembroke, Carver and Wareham. The histories of the plantings strongly suggested that all the infections had had a common origin on a bog in Wareham, where the variety had been known as "Small's No. 1." Holliston vines on ten other bogs, in Plymouth, Carver, Middleborough, Lakeville, South Hanover and Holliston, the planting in the last-named town being the original one of the variety, showed no sign of the disease. This suggests that the Holliston variety, as grown on the Cape, may be a double one, the infected strain

[1] Mass. Agr. Expt. Sta., Bul. No. 180, 1917, p. 184.

[2] Mass. Agr. Expt. Sta., Bul. No. 160, 1915, p. 100; and Bul. No. 168, 1916, p. 5.

[3] This variety is widely known as "Mammoth" or "Batchelder," but the name of its place of origin seems preferable.

perhaps having come from Wisconsin. The Bennet Jumbo variety resembles the Holliston. The fact that Holliston vines are widely infected warns against further planting of the variety.

Early Black and Howes vines much affected by false blossom were found on two bogs in Marion. The vines of these plantings came from several sources and the origin of the infection is uncertain. This disease evidently is more widely prevalent on the Cape than has been supposed. Those who start new plantings should be careful not to use vines harboring it.

Fungous Injury to Small Berries caused by Submergence.

In late July and early August, 1919, numerous tests were conducted to determine the effect of submergence on the small berries. Pieces of cranberry turf, with the vines bearing berries, were immersed in Spectacle Pond (East Wareham) in clear or mostly clear weather. The periods of submersion were one to four days long. Early Black and Howes berries from various bogs were tested comparatively in this way several times. Pride and Perry Red berries also were tried. In all cases the Howes fruit was hurt less by the submersion than that of the other varieties. It appeared that this variety usually can be flooded forty-eight hours in clear weather, while the berries are small, without serious immediate harm. Such treatment probably would impair keeping quality, however. The results with the Early Black berries varied greatly, some lots being much harmed by twenty-four hours of submersion, while others seemed little hurt after forty-eight hours; but generally this variety was the most susceptible to injury of those treated, the Pride and Perry Red being intermediate. The water did most harm when its temperature was relatively high. Some Howes lots showed but little softening when submerged in cool weather four days.

Injury incidental to submergence seemed due to rapid development of putrefactive fungi. The softening of the berry always started in a small spot which kept enlarging as long as the immersion continued, until it included the whole fruit. The softened tissue examined microscopically was found always full of mycelium.

Dr. C. L. Shear, of the Bureau of Plant Industry, and his assistants, made cultures from the softened tissues of various lots of berries from these tests. The fungi found and their relative abundance are shown in Table 1.

TABLE 1. — *Fungi found in Fruit of Summer Immersion Tests.*

Fungi.	Early Black.	Perry Red.	Pride.	Howes.	Totals.
Dematium,	2½	2	2	1	7½
Fusicoccum putrefaciens Shear,	2½	0	0	2½	5
Phomopsis,	½	0	3	0	3½
Sporonema oxycocci Shear,	2½	1	0	0	3
Penicillium sp.,	0	1	2	0	3
Pestalozzia guepini vaccinii Shear,	1	1	0	0	2
Glomerella cingulata,	1	0	0	½	1½
Acanthorhynchus vaccinii Shear,	0	0	1	0	1
Altenaria,	½	0	0	0	½
Undetermined,	1½	5	2	5	13½

The totals of the table show that most of the softening of the berries was caused by the first five fungi, and that the first two were the most active.

Spraying for the Control of Fungous Diseases.

Tables 2, 3 and 4 show the results of spraying Early Black vines with "Corona" lead arsenate used at the rate of 4 pounds to 50 gallons of water, without soap. The plots of Tables 2 and 3 were the same areas, respectively, so numbered in 1918.[1] In 1919, plots A. L. 3 and A. L. 4 were treated on June 24 and July 11; A. L. 5 on June 23, July 12 and 31; and A. L. 7 on June 24, July 11 and 24. All the plots of Tables 3 and 4 were sprayed on June 23, July 26 and August 20. The quantity of fruit stored in 1919 varied from 1 to 4 bushels for each plot or check. In 1920, 6 or 7 bushels were stored for each area of Table 3, and from 2 to 7 bushels for each area of Table 4. The effect of this spraying, shown by the percentages in the tables, except possibly those of plot B, confirms the results of like tests in previous years.[2]

[1] Mass. Agr. Expt. Sta., Bul. No. 192, 1919, p. 107.

[2] Mass. Agr. Expt. Sta., Bul. No. 180, 1917, pp. 189–192; Bul. No. 192, 1919, pp. 106, 107.

TABLE 2. — *Station Bog Early Black Spraying Plots (Fungous Diseases) treated with Lead Arsenate, 1919.*

PLOTS AND CHECKS.	Area (Square Rods).	Yield per Square Rod (Bushels).	Storage Period.	Percentage of Berries showing Decay at End of Storage.
A. L. 3,	9	.41	Sept. 16 to Dec. 12	34.39
Check 1,	6	.56	Sept. 16 to Dec. 12	47.34
Check 2,	9	.53	Sept. 16 to Dec. 12	48.11
A. L. 4,	8	.38	Sept. 16 to Dec. 11	37.14
Check 1,	8	.50	Sept. 16 to Dec. 11	41.38
Check 2,	8	.38	Sept. 16 to Dec. 13	49.98
A. L. 5,	–	–	Sept. 16 to Dec. 12	43.01
Check 1,	–	–	Sept. 16 to Dec. 12	57.82
Check 2,	–	–	Sept. 16 to Dec. 11	63.65
Check 3,	–	–	Sept. 16 to Dec. 11	65.07
A. L. 7,	8	.25	Sept. 16 to Dec. 11	47.11
Check 1,	8	.13	Sept. 16 to Dec. 11	63.56
Check 2,	8	.22	Sept. 16 to Dec. 11	60.04

TABLE 3. — *Station Bog Early Black Spraying Plots (Fungous Diseases) treated with Lead Arsenate, 1920.*

PLOTS AND CHECKS.	Area (Square Rods).	Yield per Square Rod (Bushels).	Storage Period.	Percentage of Berries showing Decay at End of Storage.
A. L. 1,	9	1.30	Sept. 18 to Dec. 3	12.06
Check 1,	6	1.33	Sept. 18 to Dec. 4	18.09
Check 2,	6	1.44	Sept. 18 to Dec. 3	24.56
Check 3,	6	1.61	Sept. 18 to Dec. 3	19.02
A. L. 2,	9	1.50	Sept. 27 to Dec. 7	18.26
Check 1,	6	1.42	Sept. 27 to Dec. 7	28.30
Check 2,	6	1.63	Sept. 27 to Dec. 7	26.35
Check 3,	6	1.92	Sept. 27 to Dec. 7	32.02
A. L. 3,	9	1.74	Sept. 27 to Dec. 6	9.88
Check 1,	6	1.86	Sept. 27 to Dec. 6	22.73
Check 2,	6	1.96	Sept. 27 to Dec. 6	25.13
A. L. 4,	8	1.70	Sept. 27 to Dec. 4	9.39
Check 1,	6	2.21	Sept. 27 to Dec. 6	25.04
Check 2,	8	2.04	Sept. 27 to Dec. 6	23.55
A. L. 5,	9	1.31	Sept. 18 to Dec. 3	8.74
Check 1,	9	1.37	Sept. 18 to Dec. 4	18.45
Check 2,	6	1.11	Sept. 18 to Dec. 3	17.96
Check 3,	6	1.15	Sept. 18 to Dec. 2	17.78
A. L. 7,	8	1.06	Sept. 18 to Nov. 30	5.27
Check 1,	8	1.06	Sept. 18 to Nov. 29	20.47
Check 2,	4	.81	Sept. 18 to Nov. 29	15.34
Check 3,	8	1.13	Sept. 18 to Nov. 30	19.17

TABLE 4. — *Eagle Holt Bog Early Black Spraying Plots (Fungous Diseases) treated with Lead Arsenate, 1920.*

PLOTS AND CHECKS.	Storage Period.	Percentage of Berries showing Decay at End of Storage.
Plot A,	Oct. to Nov. 27,	9 61
Check,	Oct. 1 to Nov. 29,	19.96
Plot B,	Sept. 10 to Nov. 26,	20 88
Check 1,	Sept. 10 to Nov. 26,	21.89
Check 2,	Sept. 10 to Nov. 26,	22.23
Check 3,	Sept. 10 to Nov. 26	22.71

The plots of Table 5 were treated in the same way and on the same dates as those of Tables 3 and 4. The results with the first plot were like those with the Early Black variety, but the fruit of the second plot showed no effect from the spraying.

TABLE 5. — *Station Bog Howes Spraying Plots (Fungous Diseases) treated with Lead Arsenate, 1920.*

PLOTS AND CHECKS.	Area (Square Rods).	Yield per Square Rod (Bushels).	Storage Period.	Percentage of Berries showing Decay at End of Storage.
Howes A. L. 1,	9	.74	Oct. 2 to Dec. 9	5 92
Check 1,	6	.42	Oct. 2 to Dec. 9	8.78
Check 2,	4½	.74	Oct. 2 to Dec. 9	8.61
Check 3,	9	.93	Oct. 2 to Dec. 8	8.80
Howes A. L. 2,	9	1.43	Oct. 2 to Dec. 9	14.66
Check 1,	9	1.07	Oct. 2 to Dec. 9	13.69
Check 2,	6	.94	Oct. 2 to Dec. 8	14.98
Check 3,	9	1 22	Oct. 2 to Dec. 9	10.09

Table 6 shows that two Early Black plots gave a reaction to calcium arsenate like that produced by lead arsenate. These plots were sprayed June 22, July 27 and August 20, the insecticide being used at the rate of 4 pounds to 50 gallons of water, without soap. Five or 6 bushels of fruit from each of these plots and each check were stored.

TABLE 6. — *Station Bog Early Black Spraying Plots (Fungous Diseases) treated with Calcium Arsenate, 1920.*

Plots and Checks.	Area (Square Rods).	Yield per Square Rod (Bushels).	Storage Period.	Percentage of Berries showing Decay at End of Storage.
A. Lime 1,	6	1.63	Sept. 27 to Dec. 6	20.85
Check,	6	1.94	Sept. 27 to Dec. 7	28.06
A. Lime 2,	6	1.39	Sept. 27 to Dec. 4	10.63
Check,	6	1.58	Sept. 27 to Dec. 1	16.52

With all the spraying plots having more than one check, the checks bordered different sides of the plot. The berries were all scoop-picked and stored in bushel crates as they came from the bog. At the end of the storage the fruit was examined by the "seven-sample" method[1] by the screeners employed at the station, under the writer's supervision, the inspector's cup of the New England Cranberry Sales Company being used for sampling. The Sales Company's hand grader was used to facilitate the work.

In both 1919 and 1920 the vines sprayed repeatedly with lead arsenate for three or more years had such a growth of runners that they were hard to scoop. As the surrounding bog showed no such development, this was clearly a reaction to the insecticide. The sprayed vines seemed to show a slight reduction in number of uprights. On the whole, the effect of the spraying on the vines was distinctly undesirable.

In 1920 Dr. Shear and his assistants made cultures of the fungi in twenty rotten berries taken at random at the end of the storage period from among the fruit of each of three of the lead arsenate plots and the fruit of the checks on each of these plots. Table 7 shows what fungi were found. Apparently the spraying had reduced both Phomopsis and *Fusicoccum putrefaciens* greatly, and had affected Glomerella, Sporonema and Dematium little, if any. These conclusions are supported by the fact that mostly negative results have been obtained in spraying Howes vines with lead arsenate, for studies in previous seasons[2] showed that on the station bog Glomerella was relatively a much more important disease of the Howes variety than of the Early Black.

[1] In this method seven samples from each crate are examined, one being taken from the surface berries of each half of the crate halfway between the middle and end; one from each half of the crate halfway between the top and bottom and halfway between the center and end; one from the very center; and one from the very bottom of each half of the crate halfway between the middle and end.

[2] Mass. Agr. Expt. Sta., Bul. No. 198, 1920, pp. 88–92.

TABLE 7. — *The Number of Cultures of Different Fungi obtained from Decayed Berries from Sprayed Areas and their Unsprayed Checks.*

Fungi.	Number of Berries giving Cultures of the Fungi [1]							
	Sprayed Plots.				Check Plots (not sprayed).			
	A. L. 2	A. L. 5	A. L. 7	Totals of the Three Plots.	Checks on A. L. 2.	Checks on A. L. 5	Checks on A. L. 7	Totals of the Checks.
Fusicoccum,	2	8	8	18	8	11	15	34
Glomerella,	11	9	7	27	3	5	2	10
Phomopsis,	0	1	1	2	2	3	5	10
Sporonema,	0	2	7	9	0	4	1	5
Penicillium,	2	0	3	5	2	1	0	3
Dematium,	2	1	1	4	1	0	0	1
Alternaria,	0	0	0	0	2	0	0	2

[1] In each case cultures were made from twenty rotten berries.

Keeping Tests with the Pride Variety.

As the Pride is the most productive cranberry variety and is not widely grown, knowledge of the keeping quality of its fruit is desirable. In a test made in a previous year this variety seemed superior to the Early Black and not greatly inferior to the Howes. In 1919 a shipping test was conducted, Early Black berries being provided by the station, three Pride lots by B. F. Vose, L. B. Handy and the Federal Cranberry Company, respectively, and two Howes lots by C. R. Rogers. Each lot consisted of one barrel of berries. All the fruit was separated, screened and packed under uniform conditions at the Carver packing house of the New England Cranberry Sales Company. It was shipped to Washington, D. C., and there stored and examined under the direction of Drs. Shear and Stevens. The results appear in Table 8.

TABLE 8. — *Results of Keeping Test of Cranberries, 1919.*

[The berries were screened at North Carver October 16, received at Washington, D. C., October 24, and stored at a temperature of 40 to 50° F. until the date given. Note that the Early Blacks and the first lot of Prides were sorted a week before the rest.]

Barrel Samples.	Percentage of Sound Berries.					
	Station **Early Blacks** (Sorted Nov. 15).	Handy **Prides** (Sorted Nov. 15).	Federal **Prides** (Sorted Nov. 22).	Vose **Prides** (Sorted Nov. 22).	Rogers **Howes** (Sorted Nov. 22).	Rogers **Howes** (Sorted Nov. 22).
Top,	41	80	56	70	72	84
1/4,	39	65	52	70	77	85
1/4,	33	65	58	84	75	84
Middle,	41	69	55	70	79	80
Middle,	52	73	50	63	76	88
3/4,	36	60	61	63	80	82
3/4,	39	69	58	68	89	82
Bottom,	49	71	60	76	83	81
Average,	41	69	56	71	79	83

Insects.

The Green Spanworm (Cymatophora sulphurea (Pack.)).

This species was unusually prevalent in 1920, the moths appearing abundantly on many bogs and the worms wiping out a fine crop promise on several bogs in Duxbury.

The moths were flying in clouds on the Duxbury bog on July 22 and also on August 2. On the former date the males outnumbered the females fully 200 to 1, while on the latter they seemed only slightly more numerous. This indicates that the species is strongly protandrous in emerging from the pupa. The males are more active than the females, but both sexes rest much among the vines. The males fly much less than those of *Epelis truncataria*, but they are flushed up easily. Several females reared in confinement and dissected before they oviposited contained from 103 to 117 eggs. The greater egg capacity of *Epelis*[1] may explain its greater prevalence. Green spanworms captured August 2 were found to be mostly through laying. The greenish-white eggs are laid singly on the old fallen leaves under the vines, and winter under the water (if the bog is flooded), hatching in the spring.

The injury done on the Duxbury bog was much like the work of the blossom worm[2] (or bud worm), the flowers being nipped off and dropped.

The Brown Spanworm (Epelis truncataria var. faxonii Minot).

This species was found in great numbers on twelve different bogs in 1919, and the moths appeared abundantly on even more in 1920. It was so much more prevalent than usual that it demanded as much attention as any cranberry pest except the gypsy moth. The writer attended to many requests for advice in checking infestations in 1920, and the insect did little harm except on a few neglected bogs, lead arsenate (3 pounds of powder to 50 gallons of water) being very effective wherever used.

The worms began hatching June 30, 1919, and July 1, 1920, probably being about normal in this respect both years. In 1919 they worked on some bogs until into August. Uncounted hundreds over a thousand of the small worms to 50 sweeps of an insect net were obtained on parts of one bog two days after hatching began there. This bog was sprayed with lead arsenate at once. It was examined again sixteen days later and 75 nearly mature worms to 50 sweeps of the net were obtained on the area most infested. These caterpillars were doing little harm, for the only notable injury on the vines was the work of the multitude of small worms that had been checked by the spraying soon after they began. The tips of the vines had made much new growth after the spraying. This was lighter green than the earlier growth of the season and showed little worm-eating. This and other observations have shown that an infestation of this insect giving less than 50 worms to 50 sweeps of the net will not do much harm

---

[1] Mass. Agr. Expt. Sta., Bul. No. 150, 1914, p. 50.

[2] U. S. Dept. Agr., Farmers' Bul. No. 860, 1917, p. 23.

when not treated. With such a light attack, it may not pay to spray if the bloom is heavy and the crop prospect good, because of the mechanical injury done in spraying. If the crop promise is poor, however, it is best to treat even a light infestation to save trouble the next year. The writer observed a case in which an infestation giving 275 worms to 50 sweeps of the net destroyed fully three-fourths of a fine prospective crop. One experienced with this pest can gauge a coming attack fairly well by the numbers in which the moths appear in mid-June.

The spraying should be done when the eggs begin to hatch, for the worms are poisoned most easily in their first stages, and they are sometimes numerous enough to destroy a fine crop promise within four days after hatching begins. Therefore an infested bog should be examined with an insect net daily from June 20 until the worms are found. If the infestation is severe and the area involved is so large that it will take several days to treat it, the spraying should begin a few days before the worms are expected, and the less heavily infested vines should be treated first. Under such conditions the work usually should start about June 26 on bogs from which the winter water has been let off before May 5.

The small worms seem usually to attack the flower buds as soon as anything, a hole commonly being eaten through the ovary. Often in moderate infestations they work like the blossom worm mentioned above, the flowers being nipped off and dropped to the ground.

When this species attacks severely enough to turn the vines brown it always destroys all chances of a crop in the following year, even if it is completely controlled that season, and sometimes patches of vines fail to recover for two or three years.

The period of activity of the green spanworm moths coincides with that of the worms of this insect, and as both species often abound on the same area, they are much confused in the minds of growers.

The Cranberry Girdler (*Crambus hortuellus* Hübner).

This pest was much more prevalent, especially in 1920, than it had been for many years. Its increase was pretty certainly due to the general neglect of resanding during and since the war.

Hitherto unreported parasites of the girdler were reared, as follows: —

1. *Cremastus facilis* (Cress.).[1] This species makes a delicate brownish-gray cocoon inside that of its host. Apparently no girdler cocoon ever contains more than one of these parasites. The adult parasites emerged June 6 and 7, 1919, from cocoons collected on a bog the former day. About 10 per cent of the cocoons harbored this parasite.

2. *Macrocentrus* sp.[1] Several cocoons of this species were found together in each of two host cocoons collected on a bog May 31, 1919. The adults emerged from one to four days later.

3. *Phygadeuon* sp.[1] The cocoons of this parasite are yellow and astonishingly tough. As with *Cremastus*, there is but one in a host cocoon.

[1] Identified by R. A. Cushman of the Bureau of Entomology.

Girdler cocoons containing cocoons of this species were collected on a bog June 6, 1919, and the adult parasites emerged May 10 and 11, 1920, their cocoon stage thus being remarkably long. It was estimated that about 10 per cent of the girdler cocoons on the bog from which these specimens came contained this parasite.

The girdler cocoons from which these three parasite species emerged were collected at South Wareham, on a bog which always is flooded in the winter and usually is flowed for a day or two in June. They were taken from an area, about 80 yards from the bog margin, from which the vines had been burned off in early May, before the thick accumulation of old fallen leaves on the ground had dried out. The burning had been done to destroy the girdler infestation, but it had not killed either this pest or the brown spanworm (*Epelis*), pupæ of which were present in some numbers.

The writer often finds barn swallows capturing large numbers of girdler moths.[1]

It was found in 1920 that 1 part of Black-Leaf 40 in 400 parts of water, with 2 pounds of soap to 50 gallons added, kills girdler moths readily. While this spray may not control the pest entirely, it probably will help greatly where other means are lacking. It probably should be used about four times, at three-day intervals, for the moths emerge from their cocoons in large numbers for a week or two. The insecticide, tried in this connection at strengths of 1 to 600 and 1 to 800 with soap, and 1 to 400 without soap, proved unsatisfactory.

The Cranberry Root Grub (*Amphicoma vulpina* Hentz.).

On July 21, 1917, some wash boilers with the bottoms removed were driven into the station bog until the vines came within a few inches of their tops. Grubs of this species gathered from another bog were put in them as follows, after which the boilers were covered tightly with cheesecloth for the rest of the summer.

TABLE 9. — *Root Grubs put in Boilers at Station Bog July 22, 1917.*

Boiler No.	Number of Grubs.	Length of Grubs[2] (Millimeters).
1,	17	8-10
2,	60	12-15
3,	21	15-20
4,	97	20-28
5,	60	28-30

[1] Forbush: Useful Birds and Their Protection, p. 346, 1907. U. S. Dept. Agr., Bul. No. 554, 1917, p. 12.

[2] The grubs of various sizes were found working together, as is common with this species, broods started in two or three different years probably being represented.

On July 8, 1919, the vines inside the boilers were removed and the sand down to the peat, about 7 inches deep, was taken out and carefully sifted. Amphicoma grubs were found as follows: —

TABLE 10. — *Root Grubs found in Boilers at Station Bog July 8, 1919.*

BOILER NO.	Number of Grubs found.	Length of Grubs (Millimeters).
1,	2	24–25
2,	5	21–25
3,	1	26
4,	5	9–11
5,	0	–

The grubs from the first three boilers were evidently what were left of those put in in 1917, larger grown. Those from boiler 4 probably were a new brood produced by beetles of the grubs put in in 1917. Grubs of the smaller sizes probably were a year or more old when put in the boilers in 1917, and the size of those taken from boilers 1, 2 and 3 in 1919 suggests that they required another year to mature. Evidently, therefore, the grub stage lasts three or four years.

On July 1, 1920, the grubs were found in numbers among the fine cranberry roots of bogs, within 3 or 4 inches of the surface. On July 28, in the same places, they hardly could be found among the roots, but were abundant 6 to 10 inches below the surface, many being in the peat under the sand. One was 4 inches deep in the peat. On December 3, in the same locations, they were 3 to $5\frac{1}{2}$ inches below the surface, the lowest being near the water table. It seems from this that the insect works deeper into the soil as a bog dries out in summer and comes up again with a rise of the water.

The Army Worm (Cirphis unipuncta Haw.).

In previous reports,[1] the fall army worm (*Laphygma frugiperda* S. & A.) and the greasy cutworm (*Agrotis ypsilon* Rott.) were mentioned as harming bogs after removal of the winter flowage in July. In 1919 a destructive visitation of the army worm under like circumstances on a bog at Mays Landing, N. J., was reported, worms of the infestation one-third to one-half grown being brought to the writer on August 8. Moths reared from these worms emerged September 9 and 10. The winter water had been let off from this bog about July 5.

On July 20, 1920, army worms, many nearly mature, were found damaging a bog at Assonet, bared of its winter flowage June 16, and on July 24 they were found abundant on a bog in Carver, bared of its flowage July 2, the largest being one-fifth to one-quarter grown. It is noteworthy, in connection with these infestations, that this pest was prevalent in most of the Mississippi Basin in both 1919 and 1920. The former year it was

[1] Mass. Agr. Expt. Sta., Bul. No. 180, 1917, p. 232; Bul. No. 192, 1919, p. 133.

reported as injuring corn or grass in the following towns in eastern Massachusetts: Wilmington, Canton, Bourne, Falmouth, Barnstable, Brewster and Chatham. That year it destroyed 20 acres of corn on one farm in Bourne. In 1920 it seriously hurt several acres of corn in Bourne.

The army worm and the fall army worm are the two more common of the three harmful insects known to infest the bogs as a result of letting off the winter water in midsummer. The outbreaks of both species nearly always start in the southern States. They are noted there by the Bureau of Entomology which forecasts their spread into the North. Such forecasts were published in both 1919 and 1920. Cranberry growers contemplating holding winter flowage very late should consult the Bureau as to the prospective abundance of these pests. The army worm probably never greatly harms cranberry bogs reasonably free of grasses except in infestations following very late removal of the winter flood.

The Cranberry Fruit Worm (*Mineola vaccinii* Riley).

In 1919 this pest did less harm than in any previous year of the writer's experience. Its reduction was to be expected from the mildness of the previous winter and the wetness of the growing season.[1] The egg parasitism (*Trichogramma*) examined ranged from 16 to 88 per cent on dry bogs, and from 0 to 37 on flowed ones.

In 1920 the insect did much more harm than in 1919, the winter before having been severe. The egg parasitism ranged from 14 to 50 per cent on dry bogs, and from 0 to 25 per cent on flowed ones.

The Black-head Fireworm (*Rhopobota vacciniana* (Pack.)).

This pest was less harmful in 1919 than in any previous year of the writer's experience. The second brood seemed to be entirely suppressed on some bogs; on others it began hatching freely, but for some cause, perhaps disease, as a rule faded out without doing much damage. In 1920 this worm was less harmful than usual, but more so than in 1919.

Results of spraying tests in 1920 support previous experience in indicating that while 1 part of Black-Leaf 40 in 800 parts of water, with 2 pounds of soap to 50 gallons added, is fairly effective in killing the worms, it is probably better economy, all things considered, to use the insecticide at the rate of 1 part to 400 parts of water. One part to 800, with the soap, kills the moths satisfactorily. At either strength the spray is safe to use when the vines are in bloom. Lead arsenate may be used with Black-Leaf 40 if the soap is left out,[2] but it should not be so used unless other pests, such as the gypsy moth or spanworms, are also to be treated, for the soap makes the Black-Leaf 40 more effective.

As cloudiness or dark water, by reducing the light reaching the plants and so lessening photosynthesis, causes a marked decrease of oxygen in the water of a cranberry bog flooding to be maintained, it seems that,

[1] Mass. Agr. Expt. Sta., Bul. No. 180, 1917, p. 227.
[2] The arsenate and soap make a burning mixture.

under such conditions of light reduction, the forty-eight-hour flooding period hitherto advocated for treating this insect may be much reduced, for the oxygen deficiency should affect the worms as well as the plants.

The Gypsy Moth (*Porthetria dispar* L.).

In 1919 this insect hurt the bogs more than any other. In 1920 it did little harm, as it was generally less prevalent and was treated much more effectively by the growers.

In 1920 Mr. Walter F. Holmes, the gypsy-moth division superintendent for Cape Cod, and the writer tested the open nozzle for treating this pest on the bogs. This is the nozzle used in the gypsy-moth work to spray tall trees from the ground. As tested it proved unsatisfactory for bog spraying, as it was hard to spray at such long range without skipping considerable areas; but it should be tried further, with smaller nozzle holes and lower pressures.

Experience and experiments in recent years have shown that this insect can be controlled readily on the bogs by —

1. *Holding the winter flowage until May 25.* This will kill the eggs laid on the bog the season before, and in most years it also will catch most of the worm wind-drift.

2. *Reflowing about May 29 for thirty-six hours.* The wind-drift is about over then, and the water will kill the worms before they do much harm unless they are unusually numerous. This flooding also will destroy other pests that may be at work, such as the false army worm (*Calocampa*), blossom worm (bud worm) and fireworm. After the gypsy caterpillars are one-third grown, a fourteen-hour flooding kills them, few getting ashore with life enough to eat afterward. They seem to thrash themselves to death in the water, as do apparently all other growing foliage-eating worms of the cranberry, except those that sew the leaves together. If the worms are very numerous, however, it is better not to delay the flooding after the above date in average seasons. The date for the earliest springs is May 24 and for the latest June 3.

3. *Spraying with lead arsenate (3 pounds of powder or 6 pounds of paste to 50 gallons of water) about May 24.* Well applied, this treatment is sure death to the worms when they are small. They are hard to poison when over half grown. In very early springs the spraying should be done about May 18; in very late ones about May 30.

4. *Keeping the maturing worms from getting onto the bogs. This is done best by:* —

(*a*) *Removing the trees, especially the oaks, for some distance back from the bog margin.* The removal of the underbrush (scrub oaks, etc.) also would help, but this seems too costly.

(*b*) *Keeping the marginal ditch cleaned out and partly full of water, and maintaining a film of kerosene or crude oil on the water during the worm-crawl period.*

Bog Management.

Experience and the results of recent experiments lead to the conclusion that winter-flowed bogs not reflowed in June should be sprayed once regularly, a few days before the vines blossom, with this mixture: —

Black-Leaf 40,	1 gallon
Water,	400 gallons
Fish-oil soap,	16 pounds

This treatment largely takes the place of the June reflow in reducing various harmful pests, especially —

1. The black-head fireworm (*Rhopobota vacciniana* (Pack.)).
2. The spittle insect (*Clastoptera vittata* Ball).
3. The girdler (*Crambus hortuellus* Hübner).
4. Leaf hoppers (mainly species of *Euscelis* [1]) and spring-tails (*Collembola*). These forms abound among the vines of bogs not reflowed, and must drain their vitality considerably. Cranberry vines often seem stimulated in growth by nicotine sprays. Probably this is usually due to the reduction of insect drains.

Resanding.

The results with two plots on the station bog that have not been sanded since 1909 are shown in Tables 9 and 10. The check areas in each case bordered different sides of the plot. The berries were Early Black and were picked and stored in 1920 on September 18. They were stored in bushel crates, 6 bushels being used in each case, and were examined November 26 to December 2 by the "seven-sample" method. No distinct effect on keeping quality from resanding was revealed.[2] These plots yielded as well as the surrounding bog until 1916.[3] Table 10 shows how since 1915 their average productiveness has fallen below that of their checks. The last five years these plots have been more thinly vined than the surrounding bog.

[1] Identified by W. L. McAtee of the Bureau of Biological Survey.
[2] Mass. Agr. Expt. Sta., Bul. No. 180, 1917, p. 219, Table 18; Bul. No. 192, 1919, p. 134, Table 14.
[3] Mass. Agr. Expt. Sta., Bul. No. 168, 1916, p. 27, Table 15.

TABLE 11. — *Sanding Plots in 1920. Effect of Resanding on Keeping Quality of Cranberries.*

Plots and Checks.	Area (Square Rods).	Resanded.	Percentage of Berries showing Decay at End of Storage.
V,	9	Not since 1909,	15.63
V (check 1),	9	Spring of 1912, fall of 1914, spring of 1917 and spring of 1919.	14.85
V (check 2),	6	Spring of 1912, fall of 1914, spring of 1917 and spring of 1919.	13.85
V (check 3),	9	Spring of 1912, fall of 1914, spring of 1917 and spring of 1919.	17.41
O,	9	Not since 1909,	13.61
O (check 1),	6	Fall of 1911, fall of 1914, spring of 1917 and spring of 1919.	18.83
O (check 2),	6	Fall of 1911, fall of 1914, spring of 1917 and spring of 1919.	17.28
O (check 3),	9	Fall of 1911, fall of 1914, spring of 1917 and spring of 1919.	12.86

TABLE 12. — *Productiveness of Sanding Plots V and O from 1916 to 1920, inclusive.*

Plots and Checks.	Resanded.	Yields per Square Rod (Bushels).						
		1916.	1917.	1918.	1919.	1920.	Average, 1916-20.	Average, 1912-15.
V,	Not since 1909,	.93	.60	1.59	.24	1.22	.92	1.250
V (checks),	Four times since 1909,	1.39	.65	2.37	.16	1.41	1.20	1.052
O,	Not since 1909,	.93	.63	1.39	.19	1.07	.84	.864
O (checks),	Four times since 1909,	1.24	.63	1.95	.15	1.19	1.03	.895

Relation of Weather to Cranberry Flooding Injury.

The station bog began the season of 1919 with fair prospects, the vines having a good supply of blossom buds. Partly to check the fireworm and partly as a test treatment of the "rosebloom" disease (*Exobasidium oxycocci*), it was flooded the night of June 16, the water being held about forty-eight hours. A day or two after the water was let off, most of the buds were found to have been killed by it. This was puzzling, as the bog had been flowed with the vines in the same stage of growth in previous years without material harm. Very hot weather had accompanied some of the former June floodings, the water temperature sometimes reaching 86° F. As the first day of this flooding (June 17) was cloudy and the second (the 18th) was not very warm, the injury hardly could have been due to temperature alone.

The writer tried in every way to find the cause of the disaster. The

effects of that June's floodings on many other bogs were investigated, and it was found that no notable injury had resulted anywhere except on bogs that had been under water June 17. That day's flooding had done much harm in all the five other cases found. It seemed, therefore, that there was something peculiarly harmful about the weather of the 17th. As that day had been darkly cloudy, comparative experiments in immersing vines in water under shade and in sunshine suggested themselves. Many such tests were made, pieces of cranberry turf with the vines being submerged in some cases in tubs and in other cases in a pond. These tests took place in late June and in July, the first vines being budded and partly in blossom, and the last lots with the bloom gone and bearing small berries. The immersion periods ranged from two to four days. The degree of shade over the shaded lots varied in the different experiments, but in no case did the light seem reduced as much as it is on a real cloudy day. In all these tests the tender parts of the shaded vines were much hurt by the submersion, while the vines immersed without shading were injured little, the contrast between the shaded and unshaded vines in the tests in which the shade was heaviest being striking.

The uniform result of these experiments seems ample proof that the continued reduction of light by cloudiness is harmful to cranberry vines under water during their rapid summer growth. This being so, dark swamp water is more likely to do harm than clear water, for it reduces the light reaching the plants more; also deep flooding must be worse than shallow, for the deeper the water the more light is cut off. These conclusions accord with effects of cranberry flowage commonly observed. Bogs flooded with dark water are oftener hurt than others, and whenever a bog is hurt either by late holding of the winter water or by reflooding, the parts most deeply submerged suffer most.

Dr. H. F. Bergman of the Bureau of Plant Industry determined from time to time the oxygen content of the water used in the immersion experiments in tubs. In his papers on this work lately published,[1] he gives what is probably the true explanation of the harmful effect of shading, by cloudiness or otherwise, in summer cranberry flooding. Apparently the injury is due to drowning of the more rapidly growing parts of the plant, the oxygen in the water being reduced below the respiratory needs of these parts too long.

As Dr. Bergman shows, photosynthesis tends to keep up the oxygen content of a bog flowage. One has only to see the many bubbles of oxygen that form on the leaves of the flooded vines in clear summer weather to appreciate this. As photosynthesis depends on light, cloudiness greatly reduces it or stops it entirely. On the other hand, respiration, the process that uses up oxygen, goes on without regard to light. Apparently for this reason cloudy weather is much more dangerous than clear weather for flooding the bogs in their season of active growth. The days of the June

[1] Ann. Rept. Cape Cod Cranb. Gr. Assoc., 1919-20, pp. 19-30. Amer. Journ. of Bot., 1: 50-58, January, 1921.

floodings are about the longest in the year. In clear weather they allow photosynthesis to go on about fifteen hours of the twenty-four, the oxygen in the water thus being replenished three-fifths of the time.

From what is known about the effect of temperature with other species,[1] a rise of 18° F. must more than double the rate of respiration in the new growth of cranberry. Therefore a combination of very cloudy weather with a high water temperature seems especially dangerous in the flooding of actively growing vines; for, while the stopping of photosynthesis allows the oxygen in the water to become much reduced, the high temperature greatly increases the need of the plants for oxygen. This was the weather combination of June 17. As already stated, the day was darkly cloudy. It was also warm for a cloudy day, the temperature at the station bog reaching 77° F.; also, as the 14th, 15th and 16th had been warm days with warm nights, the water must have become quite warm before it was put on the bog. That warm water is not notably harmful in cranberry flooding in clear weather is explained by the fact that a rise in temperature, with light abundant, increases the rate of photosynthesis almost as much as that of respiration.[2]

Water Injuries to Cranberry Buds.

When, in flooding, cranberry blossom buds are hurt by drowning (lack of oxygen) they usually are either entirely killed, the whole bud turning brown and never opening, or they are injured only on one side, in which case the point of the bud soon bends toward the hurt side, and one or two lobes of the corolla commonly turn brown. When but one side of the bud is hurt it usually opens to form an imperfect blossom, but rarely develops a berry.[3] When this drowning injury occurs it is severest in the deepest water and on the sides of the ditches.

Another bud injury was observed in 1919 in connection with the flooding of three bogs located near together. The berries on these bogs are Early Black, and the water for flooding them all has the same source. All three bogs were flooded before sunrise June 12. The water was let off the two lower ones on the night of June 13, the flooding having lasted about forty-two hours and both days having been clear. The night of June 13 was cold, the temperature at near-by bogs falling to 33° F. The water on the upper bog was held until the night of June 14, the flooding period being about seventy-two hours.

These bogs were examined a few days later. Most of the buds on the two lower ones showed a peculiar injury, their tips having turned dark red or blackish and having opened somewhat. In this condition they had

---

[1] Van't Hoff: Studies in Chemical Dynamics, trans. by Ewan, 1896, p. 126. Kuijper: Rec. Trav. Bot. Néerl., 7: 131–239, 1910. Gore: U. S. Dept. Agr., Bur. of Chem., Bul. No. 142, 1911, pp. 5–28.

[2] Matthaei; Phil. Trans. Roy. Soc., B, 197: 47–105, 1905.

[3] As might be expected, for the pistil respires faster than any other part of the flower. Maige: Ann. Sci. Nat., Bot., Ser. 9, 14: 1–62, 1911.

a distinctive appearance, with none of the marks of drowning injury. Many of the buds on the upper bog (where the water was held for seventy-two hours) showed drowning injury, but none looked like those hurt on the other bogs. These bogs were examined again late in August, and the lower ones (where the water was held forty-two hours) had little fruit, the crop being plentiful only in low places and along the ditches. On the other bog the crop was heaviest on the high parts.

The buds on the lower bogs may have been hurt by exposure to the cold when the water was let off, though no frost was seen in the vicinity that night. The fact that the buds were hurt less in the low places, as evinced by the heavier fruiting there, shows that the water tended to prevent the injury.

Blueberry Work.

To control the gypsy moth, different parts of the blueberry plantation were sprayed on June 3, 1919, with these mixtures: —

1. Three pounds of lead arsenate powder to 50 gallons of water.
2. Three pounds of lead arsenate powder and 2 pounds of Good's Caustic Potash Fish-oil Soap No. 3 to 50 gallons of water.

Both sprays killed the worms, but the one with soap burned the foliage and blossom buds badly.

No budding was done in 1919 because of a lack of good sprouts to bud into, but in 1920 it was done as follows: —

Pioneer (620A) variety, 82 buds.
Cabot (834A) variety, 208 buds.

Gypsy-moth caterpillars showed a special fondness for the growth from inserted buds, giving so much trouble that it seemed impossible to continue the work, until it was found that the caterpillars were stopped by tree tanglefoot around the bases of the sprouts.

Sixty-eight small Pioneer plants from the Bureau of Plant Industry were added to the station planting, 2 in 1919 and 66 in the spring of 1920.

The drainage of the plantation was improved by new construction in 1920.

The plantation produced 98 quarts of berries in 1919, and 147 in 1920, the bearing area being about a quarter of an acre. The fruit was sold locally at moderate prices. Most of the bearing plants are untested seedlings (four years old in 1920) provided by the Bureau of Plant Industry. A few of these seem promising, — one in 1919 yielding over 2 quarts of berries which averaged about 15 mm. in diameter, the largest measuring 18 mm. The largest berries from the plantation in 1920 were 20 mm. (about eight-tenths of an inch) through.

The proper development of the blueberry work and of the cranberry variety work requires several additional acres of rough land, and an early appropriation should be made for it.

INDEX

INDEX.

PUBLIC DOCUMENT No. 31

MASSACHUSETTS AGRICULTURAL COLLEGE

THIRTY-FIFTH ANNUAL REPORT OF THE MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

PARTS I AND II

PUBLICATION OF THIS DOCUMENT
APPROVED BY THE
COMMISSION ON ADMINISTRATION AND FINANCE

1922

THIRTY-FIFTH ANNUAL REPORT

OF THE

MASSACHUSETTS AGRICULTURAL EXPERIMENT STATION

PART I

REPORT OF THE DIRECTOR AND OTHER OFFICERS

PART II

DETAILED REPORT OF THE EXPERIMENT STATION

BEING PARTS III AND IV OF THE SIXTIETH ANNUAL REPORT OF THE MASSACHUSETTS AGRICULTURAL COLLEGE

A RECORD OF THE FORTIETH YEAR FROM THE FOUNDING OF THE STATE AGRICULTURAL EXPERIMENT STATION

CONTENTS.

PART I.

PART II.

Massachusetts Agricultural Experiment Station.

OFFICERS AND STAFF.

COMMITTEE.

Trustees.	Charles H. Preston, *Chairman*	Hathorne.
	Arthur W. Gilbert	Belmont.
	Arthur G. Pollard	Lowell.
	Harold L. Frost	Arlington.
	Carlton D. Richardson	West Brookfield.

The President of the College, *ex officio*.

STATION STAFF.

Administration.
Sidney B. Haskell, B.Sc., *Director.*
Joseph B. Lindsey, Ph.D., *Vice-Director.*
Fred C. Kenney, *Treasurer.*
Henry S. Green, A.B., LL.D., *Librarian.*
Mrs. Lucia G. Church, *Secretary to the Director.*
Miss F. Ethel Felton, A.B., *Clerk and Editorial Assistant.*

Agricultural Economics.
Alexander E. Cance, Ph.D., *Professor.*
Miss Lorian P. Jefferson, M.A., *Assistant Research Professor.*

Agriculture.
Edwin F. Gaskill, B.Sc., *Assistant Research Professor.*
Robert L. Coffin, *Investigator.*

Agronomy.
Arthur B. Beaumont, Ph.D., *Professor.*

Animal Husbandry.
Schuyler M. Salisbury, B.Sc.Agr., *Professor.*

Botany.
A. Vincent Osmun, M.Sc., *Professor.*
Paul J. Anderson, Ph.D., *Professor.*
Orton L. Clark, B.Sc., *Assistant Professor.*
Webster S. Krout, M.A., *Assistant Research Professor.*
Miss Anna M. Wallace, M.A., *Curator.*
Miss Gladys I. Miner, Stenographer.
Alyn S. Ball, *Laboratory Assistant.*

Cranberry Station.
Henry J. Franklin, Ph.D., *Research Professor in Charge.*

Dairying.
Henry F. Judkins, B.Sc., *Professor.*

Entomology.
Henry T. Fernald, Ph.D., *Professor.*
Arthur I. Bourne, A.B., *Assistant Research Professor.*
Harlan N. Worthley, B.Sc., *Investigator.*
Miss Bridie E. O'Donnell, *Stenographer.*

Farm Management.
James A. Foord, M.Sc.Agr., *Professor.*

Horticultural Manufactures.
Walter W. Chenoweth, M.Sc., *Professor.*

Vegetable Gardening and Market-Garden Field Station.
Harold F. Tompson, B.Sc., *In Charge, Market-Garden Field Station.*

Meteorology.
John E. Ostrander, A.M., C.E., *Meteorologist.*

Microbiology.
Charles E. Marshall, Ph.D., *Professor.*
Arao Itano, Ph.D., *Assistant Professor.*

Plant and Animal Chemistry.

Joseph B. Lindsey, Ph.D., *Chemist.*
Edward B. Holland, Ph.D., *Research Professor.*
Fred W. Morse, M.Sc., *Research Professor.*
Carlton P. Jones, M.Sc., *Assistant Research Professor.*
John G. Archibald, B.Sc.Agr., *Assistant Research Professor.*
Charles O. Dunbar, B.Sc., *Investigator.*
Harry L. Allen, *Laboratory Assistant.*
James R. Alcock, *Assistant in Animal Nutrition.*
Miss Margaret C. Eppler, *Clerk.*

Pomology.

Fred C. Sears, M.Sc., *Professor.*
Jacob K. Shaw, Ph.D., *Research Professor.*
Arthur P. French, B.Sc., *Investigator.*
Miss Ethelyn Streeter, *Stenographer.*

Poultry Husbandry.

John C. Graham, B.Sc., *Professor.*
Frank A. Hays, Ph.D., *Research Professor.*
Miss Ruby Sanborn, A.B., *Investigator.*
Miss Doris Tower, *Stenographer.*

Rural Engineering.

Christian I. Gunness, B.Sc., *Professor.*

Veterinary Science and Animal Pathology.

G. Edward Gage, Ph.D., *Professor.*
Norman J. Pyle, V.M.D., *Assistant Research Professor of Avian Pathology.*

CONTROL SERVICE.

Henri D. Haskins, B.Sc., *Official Chemist, Fertilizer Control.*
Philip H. Smith, M.Sc., *Official Chemist, Feed Control.*
Lewell S. Walker, B.Sc., *Assistant Official Chemist, Fertilizer Control.*
Raymond W. Swift, B.Sc., *Analyst, Fertilizer Control.*
Frank J. Kokoski, B.Sc., *Analyst, Feed and Fertilizer Control.*
James T. Howard, *Inspector, Feed and Fertilizer Control.*
Miss Cora B. Grover, *Stenographer, Feed and Fertilizer Control.*
Oliver S. Flint, B.Sc., *Analyst, Poultry Disease Elimination.*
Miss Mildred H. Hollis, *Analyst, Poultry Disease Elimination.*
John J. Smith, B.Sc., *Collector of Blood Samples, Poultry Disease Elimination.*

REPORT OF THE DIRECTOR.

SIDNEY B. HASKELL.

REVIEW OF THE YEAR.

Additions to Station Equipment.

Through appropriation made by the legislature, the Station this past year was able to supplement its land equipment through the purchase of the farm lying immediately north of its present area. By the vote of the trustees of the College this is to be known as the "William P. Brooks Experimental Farm". It contains about sixty acres of land, most of this being tillable and admirably adapted for experimental work, particularly in the two great crops of the Connecticut Valley — onions and tobacco. It is a cause for gratification that the legislature realized the need, for existing facilities have been taxed to the utmost.

In addition to the above there is promise of improvement in the Station land equipment in one other direction, this coming about through the offer from the trustees of the will of the late Miss Cornelia Warren of some fifty acres of land in Waltham, for the uses of the College. The trustees of the College have voted to accept the gift and have placed this in the custody of the Experiment Station in expectation of moving the Market Garden Field Station from Lexington to the new estate in Waltham. This area has two distinct soil types, both of them relatively uniform and typical of fairly large areas, and is in many other ways better suited for experimental work in vegetables than is our present location. At the date of making this report the transfer has not yet been finally made, nor has the project been approved by the legislature. It is to be hoped, however, that the change may be made without difficulty.

The land equipment of the Station may now be considered as complete, save only for two minor projects: the first relating to the purchase of a small area to supplement the equipment of the Cranberry Station; the second of land devoted to pasture experimental work. This last is important to the welfare of the dairy industry; and as soon as land now under the control of the Station is developed for experimental purposes, the project will be formally presented.

Changes in Organization Policy.

During the year a number of changes in administrative policy have been made, all of these with the objective of securing greater economy. Through arrangements with the treasurer's office, much of the labor of accounting is now removed from the Station office. The mailing lists of Extension Service and Station are now combined, with the work done by the former organization. This is a distinct step in advance, prevents duplication of effort, and through centralization insures lower cost of handling the Station publications. In the publication work itself the size of editions has been greatly reduced, and bulletins are now sent out to but restricted mailing lists or on request only. This eliminates waste circulation and insures, so far as may be possible, maximum returns from publication funds available. Finally, for much of the miscellaneous analytical work formerly done, a charge is now being made for that part which is primarily personal service. Despite the fact that the practice of making free analyses of agricultural products is a custom of long standing, this change has been put into effect with an astonish-

ingly small amount of criticism. The soundness of the Station position, that its funds must be expended for the benefit of the people in general rather than for the individual, seems to be generally accepted.

Changes in Staff.

Dr. H. D. Goodale, for nearly ten years in the service of the Department of Poultry Husbandry, resigned June 30, 1922, on account of ill health. Dr. Goodale came to the Station from the Carnegie Laboratory, Cold Spring Harbor, New York, and brought to the Department of Poultry Husbandry the service of a man trained primarily in biology and genetics. Despite the most discouraging conditions which have attended his work, particularly the inability to control diseases on account of deficiencies in land equipment and inability to maintain quarantine, Dr. Goodale made consistent and continuous progress in his breeding work. At the time of his leaving the Station, he had developed a flock of Rhode Island Reds from which broodiness had been largely eliminated, which was early maturing, which laid heavily in winter, and which finally had given an average of 200 eggs per bird as the annual production. It was with very great regret that Dr. Goodale's resignation was accepted.

The position of Research Professor of Poultry Husbandry has been filled by the appointment of Dr. Frank A. Hays, who entered on his duties September 28, 1922. Dr. Hays comes to the institution after service in Delaware, Iowa and Wyoming. He has already had a large amount of experience in research work of this kind.

On October 5, 1922, Dr. James B. Paige, for sixteen years head of the Department of Veterinary Science in the Station, passed away. Dr. Paige had been associated with this Station since its earlier years, and had always given most valuable service. Alike for his thoroughgoing honesty and his sound common sense, Dr. Paige will be sorely missed.

The position of Professor of Animal Pathology has been filled by the appointment of Dr. George Edward Gage, who is likewise head of the Department of Veterinary Science and Animal Pathology.

On October 1 Dr. John B. Lentz was transferred from the position of Assistant Research Professor of Veterinary Science to full-time member of the teaching staff, and Veterinarian of the College. In this position Dr. Lentz' training and experience will still be available to the Station. The position of Assistant Research Professor of Avian Pathology has been created in place of that held by Dr. Lentz, and filled by the appointment of Dr. Norman J. Pyle, a graduate of the University of Pennsylvania.

In the Control Service there have been a number of changes. Miss Ethel M. Bradley resigned July 15, 1922, as Analyst, with the position filled by the appointment of Mr. Frank J. Kokoski. Mr. Ray A. Carter resigned in June, 1922, as Collector of Blood Samples under the Poultry Disease Elimination Law, with the position filled by the appointment of Mr. John J. Smith. Under date of September 30, Miss Ann Smith, Analyst in the same service, resigned, with the position filled by the appointment of Miss Mildred H. Hollis.

During the year the title of Miss Sanborn, Clerk in the Department of Poultry Husbandry, was changed to Investigator.

By action of the board of trustees, the Departments of Agronomy, Animal Husbandry, Dairy Manufactures, Farm Management and Rural Engineering were recognized as Station departments, with the heads of these departments members of the Station staff.

Publications of the Year.

Annual Report.

Thirty-fourth annual report:

Part I. Report of the Director and Other Officers; 79 pages.
Part II. Detailed Report of the Experiment Station; 168 pages (Bulletins 201–206).
Combined Contents and Index, Parts I and II; 20 pages.

Bulletins.

No. 207. Injury to Foliage by Arsenical Sprays. I. The Lead Arsenates, by H. T. Fernald and A. I. Bourne; 20 pages.
No. 208. Leaf Characters of Apple Varieties, by J. K. Shaw; 12 pages.
No. 209. Experiments in Soil Management and Fertilization of Orchards, by J. K. Shaw; 28 pages.
No. 210. Injury to Foliage by Arsenical Sprays. II. Calcium Arsenates and Arsenites. III. Notes on Other Arsenicals, by H. T. Fernald and A. I. Bourne; 10 pages.
No. 211. Changes in Egg Production in the Station Flock, by H. D. Goodale and Ruby Sanborn; 28 pages.
No. 212. A Thirty-Year Fertilizer Test, by Sidney B. Haskell; 32 pages.

Bulletins, Technical Series.

No. 5. Concerning the Diagnosis of *Bacterium pullorum* Infection in the Domestic Fowl, by George Edward Gage; 28 pages.

Bulletins, Popular Edition.

No. 211. Changes in Egg Production in the Station Flock, by H. D. Goodale; 8 pages.

Bulletins, Control Series.

No. 18. Control of Bacillary White Diarrhœa, 1920–1921, by G. E. Gage, 8 pages.
No. 19. Inspection of Commercial Feedstuffs, by Philip H. Smith and Ethel M. Bradley; 34 pages.
No. 20. Inspection of Commercial Fertilizers, by H. D. Haskins, L. S. Walker, and R. W. Swift; 42 pages.
No. 21. Inspection of Lime Products Used in Agriculture, by H. D. Haskins, L. S. Walker and R. W. Swift; 8 pages.
No. 22. Control of Bacillary White Diarrhœa, 1921–1922, by G. E. Gage and O. S. Flint; 8 pages.

Meteorological Reports.

Nos. 397–408, inclusive, 4 pages each.

Control Activities.

Through State law, four different control activities are now being operated and administered by the Station: these being the feed and fertilizer control laws, the law for the inspection of dairy glassware, and the poultry disease elimination law. Reports on the first two activities have been published in Control Bulletins Nos. 19, 20 and 21, and that of the poultry disease elimination law in Control Bulletin No. 22. Since these reports give full details of the operations in 1922, no further mention need be made in this place. The activities under the law for the inspection of dairy glassware are similar to those of preceding years.

In addition to the above, the Station also administers the advanced registry testing work for several different breed associations. This is operated as a trust fund, the work being billed at cost plus ten per cent to allow for overhead. This fund now pays the salary of a full-time assistant, who cares for the routing of the men, keeping of the records, and other work of this nature. The Experiment Station acts only as a neutral, disinterested party for determining certain stated facts. It guarantees nothing other than the accuracy of records taken under its immediate supervision.

Extension Phases of Station Work.

As in previous years the time of several of the Station men, available for research work, is seriously diminished by calls for extension service. This is particularly the case in the Department of Veterinary Science, which in the spring of the year receives numerous calls for examination of dead chicks and dead fowl. In the Department of Botany many calls come for diagnostic service on plant

diseases; and in the Department of Entomology, for similar service in respect to injurious insects. Work of this sort is essential and is not duplicated by any existing commercial organization. It is probably impossible, or if not impossible at least impracticable, to divorce investigational work entirely from educational work of this character. It should be recognized, however, that diagnosis and analysis serve only as means to the end of improvement in certain directions. As a matter of institutional policy, it is probable that, as soon as work of this kind develops so as to be a serious drain on our investigational forces, it should be organized under the Extension Service. This need is recognized by the Extension Service, and will be met as soon as funds are available.

Co-operative Organization of Extension Demonstration Projects.

Since the Station finds it necessary to do some extension work, it follows at once that a certain amount of research work, at least of fact-finding work of a survey type, may have to be done by our Extension forces. This has been particularly the case in the field of farm management, and the technical subjects of agronomy, pomology, vegetable gardening and poultry husbandry. The field demonstrations operated by some of these departments should give valuable data worthy of permanent preservation. This value, however, depends always on the authority back of the records taken. In order that this work may be better done, and to insure preservation of such records as have value, some of these demonstrations have been organized in the Station as co-operative projects. The leader of these projects must make himself responsible for the accuracy of the work. Unless he can vouch for the records presented they cannot be accepted. It is too early as yet to speak of the success or failure of this plan. There are, however, seven projects organized on this basis, as follows:

"Poultry disease prevention and eradication"	Extension Professor Monahan.
"Artificial illumination of poultry"	Extension Professor Monahan.
"The use of nitrate of soda in apple orchards"	Extension Professor Van Meter.
"Controlling peach borers"	Extension Professor Van Meter.
"Thinning apples"	Extension Professor Van Meter.
"Comparison of results obtained in spraying with spray rod and spray gun"	Extension Professor Van Meter.
"Investigation of farm organization and labor efficiency on Massachusetts farms"	Professor Foord.

In addition to the above there are two other co-operative projects in which the expenses are met by the Station, but the salaries paid from other funds. One of these is the "Boston food supply study" carried out under the leadership of Dr. McFall; the other, "Testing low lift pumps" with the work done by the members of the Department of Rural Engineering under the leadership of Professor Gunness. These two projects are recorded in the reports on our investigational service.

REPORT ON PROJECTS.

Plant Nutrition and Soil Fertility.

The problem of soil fertility is dominant in every agriculture. It becomes more difficult as soils become older and agriculture becomes more intensive — and Massachusetts soils are old soils, and its agriculture is becoming more and more intensive. Orcharding, vegetable gardening, specialty vegetable growing such as asparagus growing or onion production, tobacco culture, cranberry culture — these are typical of the agricultural activities developing in the State. The fertility problems incident to the growing of these crops differ very greatly from those of the general farm. But even on the livestock farm there are some difficult problems, particularly on our permanent pastures. For all of these reasons, therefore, it is but natural and normal that a very large part of the Station resources should be

used in the study of soil fertility and plant nutrition problems. These various projects group themselves into three major classes: (1) fundamental problems of the soil and plant, studied through the Departments of Botany and Plant and Animal Chemistry; (2) problems in fertility practice, studied through the Departments of Agronomy, Pomology, the Cranberry Station and the Market Garden Field Station; and (3) investigation into the nature and value of fertilizer materials, carried out in conjunction with the Fertilizer Control, through the Department of Agriculture.

A complete list of fertility and nutritional projects under way follows, together with a brief report of progress during the past year.

Chemical Investigations.

Chemistry Project 6. "Lime absorption and acidity of Field A."

Professor Morse and Assistant Professor Jones.

The numerous analyses of the drainage waters from the plots of this field have been co-ordinated, and have been found to give consistent results which show that the use of ammonium sulfate exhausts the calcium carbonate much more rapidly than is the case where no nitrogen has been applied, while sodium nitrate removes less calcium carbonate than either treatment. This is true at all seasons of the year when water has flowed from the drains. Determinations of residual calcium carbonate in the soils of the different plots corroborate results from study of the drainage waters. Calcium carbonate is more abundant in the soil which has received sodium nitrate than in that with no nitrogen treatment, while it is lowest in the soil that has received ammonium sulfate. The cause is due partly to the character of the chemical and partly to the difference in amount of nitrification induced in the soils.

Chemistry Project 7. "Effect of sulfate and muriate of potash on the soils of Fields A and B."

Professor Morse and Assistant Professor Jones.

The work on winter injury of brambles is directly connected with this project.

Analyses of twigs and canes from currants, gooseberries and blackberries which have grown on soils fertilized with one or the other of the two potash salts have resulted in some evidence that there is a difference in composition produced by the different fertilizers. The proportion of sugar has been consistently lower in the wood of the various plants grown on the muriate treated plot. Starch and pentosans are not so consistent, which is possibly due to two causes: the actual differences in these constituents may not really be very wide; the methods for their determination are much more approximate than those for sugars. A qualitative comparison of the chlorine present in the ash of the two series of crops shows a much more pronounced test for the element in the series on muriate. This shows an actual absorption of chlorides.

It is fitting to remark here that the work so far can be regarded only as exploratory in character.

Chemistry Project 14. "A study of the availability of soil potash, with the object of developing a system of diagnosis for soils of the State."

Professor Morse.

Pot experiments were conducted by Mr. Coffin with similar results in growth to those obtained last year. Analyses of the crops have not yet been made.

Microbiological Investigations.

Microbiology Project 2. "Soil fertility as influenced by micro-organisms in their relation to the presence and disappearance of organic matter."

Assistant Professor Itano and Mr. Sanborn.

Several phases of this problem have already been worked out. Two papers were presented at the annual meeting of the Society of American Bacteriologists, and may be found in the following sources of information:

1. "A Micro Electrometric Method for Determination of CO_2." Abstracts of Bacteriology, V, 1, 1921, p. 5.
2. "Influence of Vitamin and Nucleic Acid on Azotobacter." Abstracts of Bacteriology, VI, 1, 1922, p. 16.

One other paper has been prepared: "The Relation of Hydrogen Ion Concentration to Azotobacter Chroococcum, Beijerinckii and Vinelandii." This was carried out in co-operation with Professor U. Yamagata of the Imperial University of Tokyo, Japan.

The work now in progress includes:

1. A study of the influence of various cover crops on Azotobacter.
2. Study of the enzymes of Azotobacter.
3. A study of the influence of various ions on Azotobacter.

In addition, the study of microbial decomposition of cellulose has been developed as far as time permits, and now includes a physiological study of the organisms isolated, and of the rate of decomposition under various conditions.

Physiological Studies.

Botany Project 1. "Optimum conditions of light for plant response."
Assistant Professor Clark.

The work under this project is conducted in field, greenhouse and laboratory. In the field, various crops have been grown under three different light intensities: (1) normal light; (2) light reduced in intensity by one layer of cheesecloth; (3) light reduced by two layers of cheesecloth. The object is to determine whether the light factor has any decided influence on the production of seed and on the growth and vigor of resulting seedlings. Seeds and tubers produced this year will be planted next year under normal and modified light conditions. Plants of the biennial type are in storage and will be replanted next year for seed production under the same light conditions in which they were grown this year. Immediate as well as cumulative effect of light intensity is under study in this phase of the work. The field space devoted to the project was considerably enlarged this year.

In the study of the influence of ultra-violet light on plant growth, little of consequence has developed. A new type of glass which absorbs both heat and the ultra-violet rays has been obtained and is being used in this work.

Study of the effect of red light in the stimulation of photosynthesis is also in progress.

Botany Project 15. "A study of plant stimulation by formaldehyde."

This project is temporarily suspended owing to changes in the staff.

Pomology Project 1. "Study of the interrelation of stock and scion in apples."
Professor Shaw.

This project was begun in 1912, and the main orchard set in 1915 and 1916. It is too early as yet to make even a progress report on this work.

Pomology Project 12. "Apple variety fruit spur study."
Professor Shaw and Assistant Professor Drain.

Certain phases of this general study have been taken over by Professors Mack and W. K. French. The former has studied the spur bearing habits of several standard varieties of apples, while the latter has investigated the effect of fertilizers on growth and fruit spur formation. Spur samples collected during the summer of 1921 are still awaiting analysis.

Pomology Project 14. "Winter injury of brambles."
Professor Shaw, Professor Morse and Assistant Professor Clark.

This project, co-operative between the Departments of Botany, Chemistry and Pomology, was organized to investigate the cause of the winter-killing of brambles as apparently brought about by differential fertilization with potash salts. See report on Chemistry Project 7, page *7a*.

Samples of wood growth were taken in the autumn of 1921 from the two potash plots and analyses have been made. Pentozan determinations by the furfurol method failed to indicate a higher content on the hardier plants from the sulfate plots. Studies by Professor Clark on herbaceous plants gave negative results.

Soil Management and Fertilizer Tests.

Agriculture Project 1. "Comparison of nitrogenous fertilizers."

Assistant Professor Gaskill.

This field has the longest continuous history of any now in the control of the Experiment Station. Unfortunately, however, three plots have had to be discontinued, namely, the two which received nitrate of soda as the source of nitrogen, and the one treated annually with barnyard manure. The proximity of the new chemical laboratory may, indeed, make it necessary to discontinue the whole project.

Agriculture Project 3. "Residual value of excess phosphate applications."

Assistant Professor Gaskill.

In the project attempt is being made to utilize reserves of phosphoric acid built up in the soil from past fertilizer treatment. During the season just past, the crop of hay produced on residual phosphorus was so nearly like that on the area having current applications, as to indicate rather marked utilization of phosphoric acid reserves.

Agriculture Project 4. "Methods of applying lime, and quantity of application."

Assistant Professor Gaskill.

No crop was produced on this field during the season just past, owing to the failure of the alfalfa seeding on account of wet weather.

Agriculture Project 6. "Top-dressing permanent grasslands."

Assistant Professor Gaskill.

The crop of 1922 is the second in this test. The experiment will be discontinued after the 1923 crop is harvested, as it should then be possible to estimate the cost of bringing back "run-out" mowings through resort to commercial fertilizer top-dressing rather than to plowing and reseeding.

Agriculture Project 7. "An attempt to restore productive fertility to worn-out and maltreated soils."

Assistant Professor Gaskill.

The use of a ton per acre of a complete fertilizer of an approximate 5–8–8 grade gave marked results in the second year of an attempt to "bring back" land which had reached the lowest level of infertility. The crop was mangels, late sown. On land which had become so poor as to give scarcely more than five bushels of corn to the acre, the yield was 18 tons; while where the land had received manure every year for thirty years, the yield was only 20 tons. On land unfertilized and unmanured for thirty years, crops of 12 to 15 tons were secured.

Botany Project 13. "Ecological study of pasture vegetation."

Professor Osmun and Director Haskell.

The use of chemical fertilizers and lime on areas of an old permanent pasture badly infested with running cinquefoil and with moss resulted in a rapid change of the predominant vegetation to white clover. The combination of potash and phosphoric acid was most effective, although maximum effect was not obtained without the use of lime applied as a top-dressing. Thus far it has been impossible to measure the effect of nitrogen. The precise relationship between the occurrence of certain plants and nutrient conditions as influenced by artificial treatments has not yet been developed.

This investigation is now being enlarged to measure the results of treatments and also the effect, if any, of treatments applied at different times, particularly in late fall or winter.

Market Garden Field Station Project 1. "Manure economy tests."
Professor TOMPSON.

The progress of this work, developed as it was to find an answer to the problem raised by increasing shortage of animal manures, indicates that the amount of manure ordinarily used by vegetable gardeners may be cut in half, the difference being made up by chemical fertilizers, without loss of crop and in some cases with significant decrease in cost of production.

Market Garden Field Station Project 5. "Growth control by means of intercropping."
Professor TOMPSON.

This project represents an attempt to better the condition of soils given up to permanent onions, through the systematic use of inter-sown cover crops. The records of the year were spoiled, however, because of attack of the onion maggot and the resultant spotted stand.

Pomology Project 5. "Comparison of cultivation and sod mulch in a bearing orchard."
Professor SHAW and Mr. FRENCH.

This project, started in the spring of 1921, attempts to find the difference in effects on growth and production between cultivation in a bearing orchard and the use of nitrate of soda in conjunction with a sod mulch. The sod plots were seeded to grass in June, and the application of nitrate of soda was reduced from 300 to 150 pounds per acre. The percentage of bloom was taken on all trees and the percentage of set on certain trees of each variety and treatment, as well as the regular growth and yield records. The trees on the areas seeded to grass (to which nitrate of soda was applied) on the whole bloomed heavier, set a little better and yielded considerably more than the trees in the cultivated plots (which received no nitrate of soda). The grass sod can hardly be expected to show any pronounced effect before the 1924 crop.

Pomology Project 6. "Comparison of clover and grass in a sod mulch orchard."
Professor SHAW and Mr. FRENCH.

The trees in the sod mulch plot receiving nitrogen have already shown the influence of the fertilizer. Up to date there are no clover residues on the potash and phosphoric acid plot which could have had effect comparable with that of applied nitrogen. It is interesting to note that under the proposed comparative treatments, that is grass plus nitrogenous fertilizer on the one hand as compared to clover with potash and phosphoric acid on the other, the latter system is handicapped at the very start.

Pomology Project 7. "Test of fertilizers in a sod mulch orchard."
Professor SHAW and Mr. FRENCH.

This orchard was seeded to grass in the fall of 1921, and the fertilizer application of 1921 repeated this year. While no effect of the fertilizer could be seen last year, there was a marked response by the trees on all the fertilizer plots this year as indicated by darker leaf color than that of the check trees. The regular records of growth, bloom and yield have been taken.

Pomology Project 8. "Test of cover crops for apple orchards."
Professor SHAW and Mr. FRENCH.

This project has been continued as last year, using the same cover crop with similar results. Timothy and redtop mixture was so promising that it was used in two of the larger orchards to try it out on a more extensive scale.

Pomology Project 15. "Orchard fertilization."

Professor SHAW.

The records of this orchard for thirty years, together with those of the Graves Orchard in South Amherst, have been studied and published in Bulletin No. 209. The new schedule of fertilizer applications has been continued and the usual records taken. The Rhode Island Greening trees bloomed heavily but there was a light set. The Baldwins, on the other hand, set heavily from a sparse bloom. The yield from the check plot was very light, due to a combination of light bloom, poor set and small fruit.

Pomology Project 16. "Test of different amounts of nitrate of soda."

Professor SHAW and Assistant Professor DRAIN.

The regular fertilizer applications have been made, and growth and yield records taken.

Pomology Project 20. "Test of fertilizers for pears."

Professor SHAW.

While the apple and pear are closely related botanically, it does not necessarily follow that they require the same fertilizer program. A pear orchard about six years old and about an acre in area, growing in sod, was divided into three parts in the spring of 1922. One part received nitrate of soda at the rate of 300 pounds per acre; the second part, a complete fertilizer of 300 pounds nitrate of soda, 300 pounds acid phosphate and 200 pounds sulfate of potash per acre; while the third part remained without fertilizer as a check. There was a prompt nitrogen response by the grass, but the trees showed slight if any response as indicated by leaf color. Growth and yield records of individual trees are kept as in other blocks.

Pomology Project 19. "Study of the effects of fertilizer limitation on fruit plants."

Professor SHAW.

The field known as the North Soil Test field, which has had a continuous history of over thirty years, has been set aside for work with fruit plants and was planted in the spring of 1922 to apples, peaches, grapes and currants. The fertilizer applications are being continued as before and are as follows:

Plot 1. No fertilizer
2. Nitrate of soda
3. Acid phosphate
4. No fertilizer
5. Muriate of potash
6. Nitrate of soda and acid phosphate
7. Nitrate of soda and muriate of potash
8. No fertilizer
9. Acid phosphate and muriate of potash
10. Nitrate of soda, acid phosphate and muriate of potash
11. Land plaster
12. No fertilizer
13. Nitrate of soda, acid phosphate, muriate of potash and dried blood.

The west halves of all plots have been limed from time to time, most recently in 1914.

While this field presents very abnormal conditions, it was felt that it should give some valuable information of the fertilizer needs of fruit plants.

No responses to fertilizer treatment were seen before mid-July, but from then on there were gradually increasing differences between the trees on the different plots. It was evident that nitrogen and potash were both needed for the peach trees. There was nothing to indicate that phosphorus was needed by the peach trees even on those plots that had had no addition of phosphorus for thirty years. Indeed the peach trees on plot 3, receiving only acid phosphate, were inferior to those on the check plots and especially so on the limed portion.

Pomology Project 18. "Comparison of cultivation and heavy mulching for apples and pears."

Professor SHAW.

Two one-half acre blocks, one of Wealthy apple and the other of McIntosh apple interplanted with Bosc pear, were divided into two parts, and one-half of each carried on the cultivation and cover crop system and the other half heavily mulched with swale hay from the neighboring lowlands. Fertilizers will be used as they seem necessary. This project is related to Projects 5, 6, 7 and 8 discussed above.

Crop and Crop Management Studies.

The studies carried on under this head are devoted mainly to the general problem of improving on existing conditions. Attempt is made to determine the adaptability of new crops as they may be introduced into Massachusetts, to find improved varieties, and to enable farmers to make selection among varieties offered; and to breed better varieties. There is also included in this group of studies work designed to develop better methods of handling our present crops.

The work under way in these several lines is as described in the following:

PLANT INTRODUCTION.

Cranberry Station Project 5. "Blueberry investigations."

Professor FRANKLIN.

This project was commenced in 1915, and is co-operative with the Bureau of Plant Industry of the United States Department of Agriculture. Preliminary tests with fertilizers were started during the year, and extensive budding continued. Planting and budding have both gone about as far as present facilities permit. More land and a propagating house are needed for this work.

Pomology Project 17. "A study of the cultivation of the high bush cranberry."

Professor SHAW.

Two hundred plants of Viburnum were received in the spring of 1921 from the United States Department of Agriculture and set out. A few of these plants bore a few clusters of berries. As soon as a crop is produced, affording a basis for selection, it is expected to carry out some work in propagation of desirable types.

STRAIN AND VARIETY TESTS.

Agriculture Project 5. "Test of meadow fescue *versus* timothy under varying drainage conditions."

Assistant Professor GASKILL and Mr. COFFIN.

The 1922 hay crop did not show any great superiority of one grass as compared to the other. Timothy gave the larger crop on the wetter portions of the field, the fescue outyielded the timothy on the drier portions.

Agronomy Project 1. "Investigation of the value of Hubam or annual sweet clover as compared to the biennial sweet clovers."

Professor MICHELS.

The spring seeding of both the annual and the biennial sweet clovers was a failure, possibly due to the late date of sowing. Germination in the late summer season was poor. The yellow sweet clover had such a weak growth as to indicate no value. It will be discarded from future tests. The Hubam made a much heavier, fuller top growth than did the biennial clover, but on the other hand the root growth of the latter was much the larger.

Market Garden Field Station Project 4. "Variety and strain test of tomatoes."
Professor TOMPSON.

Uniformity in growth conditions for the plants worked with in this test was prevented by an exceedingly high wind storm a few days after the plants were set. For this reason records of growth and behavior were not taken.

Pomology Project 2. "A study of tree characters of fruit varieties."
Professor SHAW and Mr. FRENCH.

Bulletin 208, "Leaf Characters of Apple Varieties" has been prepared and published during the year. The nursery certification work which has grown out of this project is developing and about 10,000 trees were examined this year. It is hoped to undertake further work with bud, bark, wood and growth habits this winter.

Pomology Project 13. "Study of varieties of tree fruits."
Professor SHAW and Assistant Professor GOULD.

Records of date and amount of bloom of practically all varieties of tree fruits on the college grounds, and individual tree yields have been secured for the season of 1922.

BREEDING.

Market Garden Field Station Project 6. "Improvement of Martha Washington asparagus."
Professor TOMPSON.

The second-year records of the 1,062 asparagus plants being studied in this investigation indicate that the comparative behavior of individual plants is fairly constant. The records also indicate a difference both in yield and in quality of product, due to the sex of the plant, which is the exact opposite of what was formerly thought to be the case. Thus far no practicable method of vegetative propagation of high yielding plants has been found.

Pomology Project 3. "The genetic composition of peaches."
Professor SHAW.

1922 failed to give a crop in this orchard. The trees are now old enough to warrant actual crossing work, which will be attempted in the spring of 1923 in case the fruit buds survive the winter.

ORCHARD MANAGEMENT.

Pomology Project 4. "Experiments in pruning apples."
Professor SHAW.

The average weight of 300 trees removed in the spring of 1922 indicates that the general law that pruning decreases tree growth in direct relationship to its severity holds as far as the trees under experiment were concerned.

Pomology Project 9. "Testing methods of pruning" and Pomology Project 10. "Testing of pruning methods on Northern Spy and other varieties."
Professor SHAW.

The time of summer pruning in Project 9 was changed from August to May, the purpose being to prevent undesired growth rather than remove it after it was made.

The Spy trees in Project 10 bore a small crop of apples. There seemed to be little if any benefit from either of the two pruning methods used over the unpruned trees, either in size of crop or quality of fruit.

Crop Protection.

As agriculture becomes more intensive, its susceptibility to disease and insect attack usually becomes greater. This is particularly the case in Massachusetts, which, because of its situation on the channels of world commerce, is open to injury from accidental importation of foreign insects and diseases. It is probable that as time goes on there will be increasing necessity of studies relative to crop protection. This is due in part to the danger of introduction of new diseases, and secondly to the fact that increasing value of farm crops brings about increased financial loss when these are damaged by fungous diseases or insect enemies.

Insect Enemies of Vegetation.

Entomology Project 2. "Economic importance of digger wasps."
Professor Fernald.

Because of the pressure of other duties, no work was done on this project, during the 1922 season.

Entomology Project 3. "Control of the onion maggot."
Assistant Professor Bourne.

Weather conditions the past year were such as to make the stand of onions on the experimental fields so variable as to make the records valueless for experimental purposes.

Entomology Project 4. "Control of squash vine borer."
Mr. Worthley.

Tentative control measures which were developed during 1921 were tried on a commercial scale at Amherst and at Lexington. The cost of such treatments was determined. The seasonal history of the borer in Amherst was compared with its history at Lexington so that control measures may be so timed as to be applicable to the Boston Market Garden District as well as to the Connecticut Valley.

Entomology Project 5. "Control of the squash bug."
Mr. Worthley.

The main effort has been to find a material toxic to the adult bugs but not toxic to the plants. To date these efforts have been only partially successful. The life history of the Tachinid parasite of the squash bug, *Trichopoda pennipes*, has been worked out, and its relation to its host determined. Papers on the life history of the squash bug in Massachusetts and the control measures tried, and on the parasite, are being prepared for publication.

Entomology Project 7. "Studies of insect outbreaks in various localities."
Professor Fernald.

This is a continuing project, the subject being entirely dependent upon the insects which may appear. In 1922 the conditions as related to the corn ear-worm and seed corn maggot, which were the insects studied in 1921, were continued and concluded; and the appearance of the birch leaf skeletonizer and the apple and thorn skeletonizer led to their study as well.

Entomology Project 8. "Pest limits in Massachusetts."
Professor Fernald.

Data on this subject are gathered each year as they appear and can be obtained. Some additions were made in 1922.

Entomology Project 9. "Number of generations of codling moth in Massachusetts as related to advisability of spraying for the second generation."

Assistant Professor Bourne.

The accumulation of data on the codling moth has now reached a point where, with good fortune, final results may be anticipated in the course of two or three seasons. Co-operative work with a fruit grower in the Nashoba fruit district has added value to the work, giving a broader knowledge of conditions in Massachusetts.

Entomology Project 10. "Hatching dates for scale insects."

Assistant Professor Bourne.

The necessary observations for 1922 have been made and recorded. To be of value, these records should be made over a long period of years, to insure inclusion of years of abnormal conditions as well as normal ones. The behavior of the insects under normal conditions has been determined with considerable accuracy. Their reaction to abnormal seasonal conditions, such as very open, mild winters, or unusually cold winters, makes further study advisable. Records on other points in the life cycle of these scales have been secured, with especial reference to the possibilities of their furnishing more accurate data on this problem.

Cranberry Station Project 1. "Injurious and beneficial insects affecting the cranberry."

Professor Franklin.

The more important results of the year's operations were the following:

A very effective control for the root grub (*Amphicoma vulpina* Hentz.), by soaking the soil with a solution of sodium cyanide, was developed.

A satisfactory control for the yellow-head fireworm (*Peronea minuta* Rob.) by killing the moths with a spray of nicotine sulfate and soap in the dormant season was perfected. Experiments also showed that this pest can be controlled with a lead arsenate spray used at the time and strength to be most effective against the gypsy moth.

It was found that the red-striped fireworm (*Gelechia trialbamaculella* Cham.) can be controlled well with a nicotine sulfate and soap spray applied while the worms are in the tips of the vines.

Dusting with nico-dust to control the black-head fireworm (*Rhopobota naevana* Hübner) proved effective but not practicable because of the expense.

Extensive spraying experiments to discover a cheaper control for black-head fireworm were conducted, with mostly negative results.

A fungus, apparently a new species of *Entomopthora*, was found causing such an epidemic among the black-head fireworms on one bog that it seemed an almost perfect control. The fungus was successfully cultured on fish. It presents interesting possibilities for further control work.

Important observations were made on the phenomenon of the occasional marked disappearance of black-head fireworm eggs while covered by the winter flood.

Many new facts were learned concerning the life histories of the following minor cranberry pests:

1. *Cacoecia parallela* Rob.
2. *Sparganothis sulfureana* Clemens.
3. *Noctua c-nigrum* L.

The work of the fruit worm (*Mineola vaccinii* Riley) was observed to be light in spite of the fact that the egg parasite (*Trichogramma minuta*) was much less prevalent than normally. The egg hatching of this pest was earlier than usual, so the worms did little harm among stored berries. Further attempts to discover a practicable means of control by wetting the cocoons with chemicals during the dormant season resulted negatively.

Plant Disease Control.

Botany Project 3. "Tobacco investigations and a study of so-called tobacco sick soils."

Professor Osmun and Professor Anderson.

This project embraces a study of soil reaction as a means of controlling root-rots of tobacco; also a study of the effects of soil reaction on the growth and development of

tobacco. During the last season, further study was made of the influence of cover-cropping and liming on the development and effect of black root-rot, caused by *Thielavia basicola*, and considerable data were obtained. An important feature of this year's field work was the successful infestation by artificial means of experimental field plots with Thielavia. With permanent plots known to be infested with this fungus and others free from it, valuable results should be obtained in the next few years.

Botany Project 4. "Investigations of the methods of controlling lettuce drop."
Professor OSMUN and Assistant Professor KROUT.

The work on this project has been completed. The investigation involved preliminary study of the reaction of the drop fungus, *Sclerotinia libertiana*, to various factors and extensive testing of these factors in their relation to the control of the disease in the greenhouse. The net practical result is the definite determination that the disease may be controlled with relatively little expense by treating infested soil with formaldehyde. A 1–100 solution applied to the surface of the soil at the rate of one gallon to the square foot was found efficacious. It was found also that treatment must begin in the seed-bed to prevent infection of young plants before transplanting to the main house. Details of practice were worked out in some of the commercial houses of the State.

Botany Project 5. "Experimental spraying for the control of cucumber mildew under glass."
Assistant Professor KROUT.

Bordeaux gave slightly better results this past season than did a copper-lime dust. Full control, however, is not yet obtained.

Botany Project 6. "Investigation of onion diseases."
Professor OSMUN and Professor ANDERSON.

As stated in the last report, the work on this project has been focused on a study of onion smut and its control. Technical Bulletin No. 4, "Development and Pathogenesis of the Onion Smut Fungus", distributed early in the present year, is a report of some of the more technical features of this work. Field tests of formaldehyde applied at different concentrations and rates were continued this year. In co-operation with the Department of Rural Engineering, the apparatus for applying formaldehyde has been perfected to the extent that errors due to uneven distribution of the fungicide have been eliminated. The development of this equipment renders advisable the continuance of field tests for at least one more season. The use of the new equipment by practical growers gave some very interesting and significant results.

Botany Project 9. "Investigation of carrot blight."
Assistant Professor KROUT.

The work on this project was conducted along the same lines as reported last year. Considerable attention was given to study of the etiology of the disease and it has been definitely established that the pathogene is a Macrosporium. The incubation period has been determined and physiological studies of the organism are in progress. In the field, considerable benefit was shown from spraying with Bordeaux mixture, but definite conclusions can be drawn only from the results of several years' work.

Botany Project 10. "Apple disease control investigations."
Assistant Professor KROUT.

The work on this project has been confined almost wholly to an investigation of the control of scab. Very satisfactory progress has been made and much of importance to the practical orchardist has resulted. It has been definitely established that the McIntosh apple, which is very susceptible to attack by scab, can be protected against this disease by spraying with fungicides. Results from dusting also have been excellent, but further tests are necessary. The best results have been obtained by the use of a 3–10–50 home-made Bordeaux mixture for the pre-pink and pink applications, followed by liquid lime-sulphur, 1–50, for the summer sprays. The most satisfactory results from dusting were obtained with finely ground sulfur. Copper-lime dust proved

effective in controlling scab, but serious russeting of the fruit by this material definitely eliminates it as a possible apple fungicide, at least for summer application.

Meteorological records were kept and important observations on the relation of meteorological conditions to sporulation, spore ejection and infection by the scab fungus were made. These data, taken over a series of years, will be invaluable in establishing a definite and permanent spraying or dusting schedule for the State.

Early in the year the leader of this project, Mr. W. S. Krout, established his residence in the eastern part of the State. This has enabled him to keep in more intimate touch with the field work and has made possible considerable expansion over last year's plan.

Botany Project 14. "Investigation of control of tobacco wildfire."

Professor ANDERSON.

The disease known as Wildfire has created a grave situation in the tobacco growing industry of the Connecticut Valley. The seriousness of the outbreak the last season, and consequent imperative need of solving the problem of control, made a constant demand on the time of the leader of this project, as well as of others of the department. The importance of thoroughly familiarizing himself with the disease, both in the seed-bed and field, kept the investigator out of the laboratory and on the tobacco farms a considerable portion of the time. In this way much information was gathered which will prove useful in the furtherance of the investigation.

Botany Project 16. "Relation of soil character to occurrence of onion smut."

Professor ANDERSON.

No progress on this project was made during the past year, on account of lack of time.

Cranberry Station Project 2. "Cranberry Disease Work."

Professor FRANKLIN.

This project was conducted, as heretofore, co-operatively with the Bureau of Plant Industry of the United States Department of Agriculture. Extensive culture work was done to discover the variation in the cranberry fungus flora among different classes of bogs, especially with reference to differences in their flooding.

Studies were pursued to determine more definitely the relationship of the weather to deterioration of cranberry keeping quality from the activity of putrefactive fungi.

Extensive tests were conducted to determine the effect on cranberry keeping of the Wisconsin method of picking known as "water-raking." This was found to be very harmful.

Extensive storage tests were also made to determine the effect on cranberry keeping of picking during the heat of the day as compared with picking late in the afternoon. The harmful effect of the former was clearly demonstrated.

SPRAY MATERIALS — THEIR NATURE AND USE.

Botany Project 17. "Potato spraying-dusting."

Professor OSMUN and Professor ANDERSON.

This project has for its main object the making of comparative tests of home-made Bordeaux mixture and copper-lime dusts for combating late-blight and other leaf diseases of the potato.

The conclusions from the first year's work are:

1. Dusting with hand dusters has not been as efficient as spraying with a power sprayer.
2. Dusting by hand costs more than power spraying.
3. The percentage of rotten potatoes was higher in the treated plots than on the check plots. This was probably due to the fact that the vines on the check plots dried earlier and the moisture conditions were then less favorable to development of the disease than where the soil remained covered several weeks longer with a dense mat of vines.
4. Both spraying and dusting resulted in considerable increase in yields over the checks. Spraying gave the greater increase.

Chemistry Project 5. "Chemistry of arsenical insecticides."
Professor HOLLAND and Mr. DUNBAR.

This project is no longer confined to arsenical insecticides, but has practically become a study of the chemistry of insecticides and fungicides. The work is in large measure co-operative with other departments of the State and Station, and is largely confined to analytical work.

It has furnished needed information relative to various types of commercial sulfur compounds, although as yet scientific entomological and pathological data are lacking for the interpretation of analytical results in terms of toxicity, or preferably of efficiency. This in a measure is also true of waste tobacco.

Chemistry Project 13. "A new method for the analysis of dry lime-sulfur mixtures."
Assistant Professor JONES.

Work on this project has been completed, and report submitted for publication.

Chemistry Project 20. "A study of the fundamental factors affecting the suspension, adhesiveness, toxicity and general efficiency of copper fungicides."
Professor HOLLAND and Mr. DUNBAR.

The work outlined is very extensive, including chemical, physical and pathological studies of a considerable variety and large number of compounds, requiring more or less co-operation by the Departments of Botany and Physics, and final verifications by field experiments. A portion of the literature has been reviewed, preliminary work on production of some of the compounds undertaken, stability and certain physical properties have been noted, and hundreds of suspension tests have been conducted to determine the effect of different amounts of lime under varying conditions and the influence of protective colloids and deflocculating agents.

Entomology Project 1. "Studies of causes of burning of foliage by arsenicals."
Professor FERNALD and Assistant Professor BOURNE.

This work has been completed, and Bulletins Nos. 207 and 210 of this Station give the results with lead arsenate, lime arsenate and some other arsenicals. A third bulletin, on Paris green, is in preparation.

Entomology Project 12. "Determination of the best strength of lime-sulfur."
Assistant Professor BOURNE.

Tests of various dry sulfids have been made under differing conditions, in comparison with different strengths of the liquid lime-sulfur. The tests have not sufficiently covered the ground as yet to make a report of results possible.

Entomology Project 13. "Study of the possible injurious effects of Scalecide on trees."
Assistant Professor BOURNE.

Tests of this material must be continued for several years before results can be reported.

Entomology Project 14. "Does spraying orchards kill bees?"
Assistant Professor BOURNE.

The investigations thus far have been quite suggestive, particularly indoor ones, but the inclement weather following the "calyx spray" out of doors last spring makes further studies necessary.

Entomology Project 15. "Determination of efficiency of nicotine sulfate dusts."
Assistant Professor BOURNE.

The nicotine sulfate dusts proved very effective in nearly all tests. The high prices of these dusts, however, often prohibit their use. Dusts of ground tobacco, reinforced

with nicotine sulfate did not give as satisfactory results, chiefly because of their inferior physical qualities. Comparative tests of superfinely ground tobacco dusts have been planned for another season.

Entomology Project 16. "Investigation of materials which promise value in insect control."

Assistant Professor Bourne.

This is a continuing project covering materials as they may appear. This season two materials were tried out — Derris and Flyosan. The tests with Derris in its various forms were quite satisfactory as far as they went, and further tests of this material will be made the coming year. When these tests have been completed a final report on Derris can be made. Flyosan in some of the tests also gave good results, but more studies of it are necessary before full statements would be advisable.

Pomology Project 11. "To test new spray materials as they become commercially important."

Professor Sears and Assistant Professor Gould.

The following materials were tried out this year in comparison with standard liquid lime-sulfur and arsenate of lead: Bordeaux mixture 3–10–50, Nurexo Bordeaux Lead, Nurexo Spraydried, Celesto, Sulfurex, Sulfocide, Sulco V-B, Dry Lime Sulfur, Nurexoform Lead, Calcium Arsenate and Cal Arsenate.

While some of these materials gave good results, none of them gave promise of sufficient merit to replace liquid lime-sulfur and lead arsenate.

Animal Nutrition.

The use of purchased concentrates, mixed or unmixed, is the salient characteristic of Massachusetts animal industry. The cost to the industry, and finally, of course, to the consumer of its products, is immense; possible waste, in case the materials are unwisely used, or bought on the basis of ignorance instead of knowledge, enormous. The work of the Station in this direction has, therefore, two objectives: first, to develop a basis for the productive feeding of these articles; and secondly, to measure the characteristics of various feedstuffs, so that dairymen may have a sound basis of purchase.

Digestibility of Feeding Stuffs.

Chemistry Project 2. "Digestion experiments."

Professor Lindsey and Assistant Professor Archibald.

In addition to digestion experiments made in connection with projects 12 and 19, one experiment was made with cocoa dust, with results incorporated in manuscript already prepared on "Digestibility of Cattle Feeds."

Chemistry Project 9. "Determining the digestibility and metabolizable energy in feeds for horses."

Professor Lindsey and Assistant Professor Archibald.

Final report is now being prepared for publication.

Chemistry Project 12. "Attempting to improve the nutritive value of grain hulls."

Assistant Professor Archibald and Professor Lindsey.

Considerable progress has been made on this project. In addition to the treatment and determinations of digestibility of oat and rice hulls already reported, the following materials have been treated and the influence of treatment on digestibility determined: — namely, barley hulls, cottonseed hulls, and flax shives. In addition to the regular analysis, determinations of starch, galactan, pentosans, and lignin have been made on the natural and treated materials, and determinations of the above substances are now being made in the feces.

It can be said that the digestibility of the barley hulls has been greatly improved, but the treatment has been substantially without effect upon the cottonseed hulls and the flax shives. The method of treatment — namely, with dilute sodium hydrate — would probably not prove economical on a large scale.

Animal Feeding.

Chemistry Project 10. "Experiments in feeding pigs."
Professor Lindsey and Assistant Professor Archibald.

This project consisted in the taking of records on feeding different amounts of semi-solid and dried buttermilk. Results indicate that these materials are uneconomical when used for pork production. Work under this project is completed, but results have not yet been submitted for publication.

Chemistry Project 16. "Vitamines as aids in the production of growth in pigs."
Professor Lindsey.

As with the above, work has been completed, temporarily at least.

Chemistry Project 17. "Attempting to secure a substitute for milk in the growing of young calves."
Professor Lindsey and Assistant Professor Archibald.

Four different materials or combinations of materials were used as milk substitutes, with a total of twenty-three calves used in the investigation, but with four discarded as unsatisfactory. In these different mixtures limited amounts of soluble blood flour, dried skim milk, oat flakes, corn meal, wheat middlings, coconut meal, peanut meal, linseed meal, starch, glucose, milk sugar, calcium chloride and salt were used. Fair results were secured.

Chemistry Project 18. "To determine the mineral constituents of forage crops."
Professor Lindsey and Assistant Professor Archibald.

This study has been fruitful in two directions: first, the collection of about sixty samples of coarse fodders, principally hay and corn silage, from different parts of the State; and secondly, determination of the mineral constituents in the ordinary concentrates which are used in the State. It is expected that this work will be completed during the coming winter.

Chemistry Project 19. "The value of inorganic calcium phosphate in the promotion of growth and milk production.
Professor Lindsey and Assistant Professor Archibald.

Up to date no effect favorable or otherwise of feeding inorganic calcium phosphate to cows, young stock and sheep has been noted. Despite this failure, however, these inorganic salts are widely used in the State as constituents of animal feeds. Their value is yet to be proven.

Miscellaneous.

Chemistry Project 3. "Summer forage crops."
Professor Lindsey.

Very little work was done on this project. There are no results worthy of extended comment.

Chemistry Project 4. "Record of the station herd."
Professor Lindsey.

As in previous years complete records on the food cost of milk produced by the station herd have been kept.

Studies of Heredity in Poultry.

The Massachusetts poultry industry is essentially intensive. It operates fairly large flocks, but on relatively small areas. Most of the food consumed is purchased, imported largely from the grain sections of the West. In order that the Massachusetts industry may compete with that of other sections of the country, it is necessary that the stock be of the highest possible grade. This fact gives a peculiarly important economic significance to the work grouped in the following:

Poultry Husbandry Project 1. "Broodiness in poultry."

Professor Hays.

The broody trait in poultry is being studied from the following angles:

1. Possibility of establishing a strain of broody-free Rhode Island Reds by systematic matings in pedigreed lines. An approach to this goal has been made in some families.
2. Specific intensification of broodiness by the pedigree system of matings.
3. The behavior of the factor or factors for broodiness in crosses.
4. The physical relationship of different organs to broodiness.

Poultry Husbandry Project 2. "To determine the mode of inheritance of various characters in poultry, and to study factors governing form and function."

Professor Hays.

The basic idea for which this project has been carried is the analysis of the mode of inheritance of factors for egg production. The results seem to indicate that at least four or five pairs of factors are concerned. Progress of a very definite character has been made by handling these factors as units in breeding.

Human Food.

The increasing cost of food products has brought about the necessity of more attention being given to the conservation of food. Conservation essentially requires control of those forces and agencies which cause decay and loss; and as a first step a study of the conditions under which these agencies develop. The very small amount of time given to this subject at this Station is not a measure of the importance of the work. In fact the well-being of the great food-consuming population of the State would be furthered were this work to be greatly increased.

Microbiology Project 1. "Microbiological investigations in milk."

Mr. Avery and Mr. Neill.

The following articles have been prepared during the year:

"A Biological Study of the Hemolytic Streptococci from Dairy and Human Sources: The Differential Reaction of Methylene Blue." Roy C. Avery.

"A Review of the Literature of Lactic Acid Fermentation." James M. Neill.

"A Study of the Characters of the Streptococci of Dairy Lactic Acid Fermentations, with Special Reference to the Present Status of the So-called *Streptococcus Lacticus* Group." James M. Neill and Roy C. Avery.

"A Comparative Study of Different Types of Streptococci, with Special Reference to the Peptolytic Activity of the Lactic Group." James M. Neill.

At the present time, however, this work is at a standstill, owing to the fact that the men involved have left the institution or become burdened with other work.

Microbiology Project 3. "Canning investigations in the light of normal and resistant organisms in continuous, fractional and pressure methods of sterilization."

Professor Marshall and Mr. McCrimmon.

The first stage of this investigation is practically complete, although verification of the results is essential and an extension of certain determinations must be made. It is, however, being retarded owing to the resignation of Mr. McCrimmon.

Agricultural Economics.

The status of agriculture at any particular time and place is always the resultant of economic forces working in conjunction with those other forces which control the condition or productivity of the soil and the possibility of growing certain crops. Massachusetts has been slow to recognize this fundamental principle. It has failed in supporting economic research in agriculture in the way which the importance of the subject necessitates. The future of New England agriculture probably depends in large measure on economic conditions; and likewise the future of New England and Massachusetts as industrial units depends on the national development and maintenance of those economic conditions which will make possible continued production of food in suitable quantities. Much of the high cost of living, of which we hear so much complaint, is due not to deficiency in local production, but rather to avoidable waste in handling farm products.

Work has been done during the past year under the following projects:

Agricultural Economics Project 1. "Local balance of trade in farm products."
Assistant Professor JEFFERSON.

Study under this project has been continued. In addition to the material secured in Fitchburg, the gathering of similar information has been carried on in New Bedford so far as it is available for that city.

The local farm products of the vicinity of New Bedford are sold in that market without system of any sort. These products are chiefly vegetables, although a small quantity of fruit is also grown. Each grower sells his own produce in the way which appeals to him. Some few sell to the wholesalers, but the most common method is for the grower to stop at the first grocery store he reaches as he drives into the city, sell what he can, and go on to the next. Naturally, this brings each grower into competition with every other, reducing the price each one receives.

No local products are shipped out of New Bedford, and the local production falls far short of supplying the needs of the city, except in the case of turnips.

A large part of the milk supply is likewise local, but considerable quantities are received at certain periods from outside sources. Some of it comes from Maine and New Hampshire, but all is received through the Boston distributors.

There is very little local slaughtering done in New Bedford, although there are two local slaughterhouses, one in the city and the other across the river in Fairhaven.

Agricultural Economics Project 2. "Methods and cost of distribution of tobacco, onions and potatoes."
Professor CANCE and Assistant Professor JEFFERSON.

An investigation of the supply and distribution of Connecticut Valley onions, already under way, was completed and the manuscript prepared for publication.

In addition to the preparation of this manuscript, material is at hand for a second, relating to the price of onions.

Agricultural Economics Project 7. "Boston food supply study."
Professor MCFALL.

This project was formally approved in July, 1922, on a co-operative basis between the Experiment Station and Extension Service. A large amount of time and energy has been expended in outlining the study and carrying on certain preliminary work. As organized, the leader of this project spends a part of each week in Boston, overseeing the work of a number of graduate students who are taking as their thesis problem certain of the subdivisions of the larger study. At the present time fourteen students are so engaged: three being from Boston University and eleven from the Massachusetts Institute of Technology. Certain other investigators are likewise co-operating, but in an informal way. The State Department of Agriculture is assisting in certain broader phases of the work. The committee on agriculture of the Boston Chamber of Commerce has co-operated in making a comparative study of the market reports of all public and private agencies reporting Boston markets. A certain amount of the financing of this work is done directly through a co-operative agreement with the Bureau of Agricultural Economics of the United States Department of Agriculture. Naturally, in its present formative stage, concrete results cannot yet be reported.

Rural Engineering.

The following project represents the first experimental work done by the Department of Rural Engineering since its formal organization as a Station department.

Rural Engineering Project 1. "Testing Low Lift Pumps."

Professor GUNNESS.

This project is co-operative between the Cranberry Station and the Department of Rural Engineering. It was made necessary by the fact that there has never been a comprehensive study made of the large capacity, low lift pumps as used so largely in the Massachusetts cranberry industry. The work occupied a large portion of the summer of 1922. Manuscript has been prepared and submitted for publication, the project in its present form being therefore complete.

Meteorological Studies.

The work of the Station in this direction consists in part of the taking of data at the home station as indicated by the following; and in part in the definite application of meteorological data to certain definite agricultural problems, notably that of cranberry bog management and secondly the relation of weather to insect development.

Meteorology Project.

The recording day by day of meteorological phenomena, and the publishing of monthly summaries for distribution to parties interested has been continued. The year just closed was the thirty-fourth over which this work has continued. When combined with the records taken by the late Professor Snell, the Station has an unbroken meteorological record of eighty-seven years. Work of this kind becomes more and more valuable as such records accumulate.

Entomology Project 11. "Study of area of the late frosts as shown by insect distribution."

Professor FERNALD.

More light on this subject has been obtained during 1922. It will require many years for completion, but takes annually only the time necessary to record the data obtained.

Cranberry Station Project 3. "Weather observations with reference to frost prediction."

Professor FRANKLIN.

As in past years, reports were telegraphed daily to the district forecaster at Boston. Further frost records were accumulated for study. Distribution of Station frost warnings was continued with the financial aid of the Cranberry Growers' Association.

METEOROLOGICAL OBSERVATIONS.

DEPARTMENT OF METEOROLOGY,

PROF. J. E. OSTRANDER, HEAD.

Annual Summary for 1922.

Pressure (in Inches).

Maximum reduced to freezing	30.36, Jan. 25, 10 A.M.
Minimum reduced to freezing	28.60, Oct. 11, 12 P.M.
Maximum reduced to freezing and sea-level	30.70, Jan. 25, 10 A.M.
Minimum reduced to freezing and sea-level	28.92, Oct. 11, 12 P.M.
Mean semi-daily reduced to freezing and sea-level	30.058
Annual range	1.78

Air Temperature (in Degrees Fahrenheit).[1]

Highest	94.0, July 12, 4.00 P.M.
Lowest	—13.5, Feb. 18, 7.30 A.M.
Mean hourly	47.2
Mean of means of max. and min.	47.8
Mean sensible (wet bulb)	43.0
Annual range	107.5
Highest mean daily	76.7, Aug. 16
Lowest mean daily	—0.8, Feb. 17
Mean maximum	58.3
Mean minimum	37.3
Mean daily range	21.0
Greatest daily range	43.5, Apr. 10
Least daily range	3.5, Nov. 7

Humidity.

Mean dew point	39.2
Mean force of vapor	.380
Mean relative humidity	78.7

Wind.

Prevailing direction	West

Summary.

South Southwest	19 per cent
Northwest	12 " "
North	10 " "
West Northwest	10 " "
Southwest	10 " "
Other directions	39 " "
Total movement	49,970 m.
Greatest daily movement	467 m., Dec. 6
Least daily movement	12 m., Jan. 17
Mean daily movement	137 m.
Mean hourly velocity	5.7 m.

Maximum pressure per square foot, 30.0 lbs., =78 m. per hour, Jan. 22, 12 M., W.

Maximum velocity for 5 minutes, 42 m. per hour, Jan. 22, 12 M., W.; June 12, 2 P.M., W.N.W.

Precipitation (in Inches).

Total precipitation, rain or melted snow	45.94
Snow total in inches	$58\frac{3}{4}$
Number of days on which .01 or more rain or melted snow fell	120

Weather.

Mean cloudiness observed	45 per cent
Total cloudiness recorded by Sun Thermometer	1,932 hrs. =43 per cent
Number of clear days	117
Number of fair days	127
Number of cloudy days	121

Bright Sunshine.

Number of hours recorded, 2,522 hrs. =57 per cent.

Dates of Frosts.

Last	May 12
First	Sept. 19

Dates of Snow.

Last	April 23
First	Nov. 24
Total days of sleighing	74

Gales of 50 or More Miles per Hour.

Jan. 22, 78 m., W.; Mar. 7, 63 m., S.; April 20, 53 m., W.N.W.; June 12, 56 m., W.N.W.; July 8, 57 m., S.S.W.; Dec. 29, 57 m., N.

[1] Temperature in ground shelter.

REPORT OF THE TREASURER.

FRED C. KENNEY.

United States Appropriations, 1921–22.

		Hatch Fund.	Adams Funds.
Dr.			
To receipts from the Treasurer of the United States, as per appropriations for fiscal year ended June 30, 1922 under acts of Congress approved March 2, 1887 and March 16, 1906		$15,000 00	$15,000 00
Cr.			
Adams:			
By salaries	$14,947 50		
Labor	52 50		
	$15,000 00		15,000 00
Hatch:			
By salaries	$14,632 50		
Labor	367 50		
	$15,000 00	15,000 00	

State Appropriations, 1921–22.

Cash balance brought forward from last fiscal year	–
Cash received from State Treasurer	$99,152 86
fees	18,648 95
sales	9,690 25
miscellaneous	378 20
	$127,870 26

Cash paid for salaries	$60,164 33
labor	17,459 50
publications	2,017 25
postage and stationery	1,767 69
freight and express	429 75
heat, light, water and power	745 56
chemicals and laboratory supplies	3,049 88
seeds, plants and sundry supplies	2,290 32
fertilizer	689 11
feeding stuffs	1,386 20
library	635 79
tools, machinery and appliances	1,167 54
furniture and fixtures	987 31
scientific apparatus and specimens	292 09
livestock	230 82
traveling expenses	4,819 60
contingent expenses	10 00
buildings and land	1,010 12
Remitted to State Treasurer	28,717 40
Total	$127,870 26

BULLETIN No. 207.

DEPARTMENT OF ENTOMOLOGY.

INJURY TO FOLIAGE BY ARSENICAL SPRAYS.

I. THE LEAD ARSENATES.

BY H. T. FERNALD AND A. I. BOURNE.

It has long been known that arsenical poisons sprayed upon foliage will at times produce injury, or a "burning" of the leaves. For this, four explanations have been offered, viz., (1) that the arsenic (either As_2O_3 or As_2O_5, as the case might be) was present in the material, uncombined with any base; (2) that it was so loosely combined with the base as to become liberated from it during the addition of water in preparing it for application to the foliage; (3) that this liberation took place more or less gradually on the leaves after the spray had been applied, as a result of influences acting upon the material through the air; and (4) that injury was due to the presence of injurious impurities in the material.

Faulty methods of manufacture might easily result in producing a substance containing some arsenic, either free or so poorly combined that upon the addition of water the combination would break up, at least to some extent. The use of poor materials from which to make the lead arsenate might very possibly result in the presence of injurious substances. The liberation of arsenic upon the tree by atmospheric influences, however, comes distinctly in a different class; and the statement sometimes made, that spraying a tree with water under the right conditions may result in burning, if true, also suggests that atmospheric conditions must not be overlooked. The entire problem, therefore, of ascertaining what factors are really responsible for foliage injury following arsenical spraying has been investigated during a period of about ten years.

This bulletin reports the results of this work with the various lead arsenates. Similar reports upon arsenates of lime and Paris green are nearly ready for publication, together with notes on a number of other arsenicals which have been tested more or less.

The planning of the project, the plotting and analysis of the results, and the preparation of the material for publication are the work of the senior

author; the preparation and application of the sprays, and the observations to determine their effects, were carried out by the junior author; the chemical analyses and all the chemical work involved were done by Dr. E. B. Holland and his assistants of the Department of Plant and Animal Chemistry of the Experiment Station, and to him and to those who worked with him the authors desire to express their appreciation of the efforts made to establish this work on a firm chemical basis.

Materials.

To eliminate the possibility that injury was caused by impurities in the spray materials, pure arsenates were first sought. A definite knowledge of the action of these appeared to be desirable, as, if injury resulted from their use, it seemed probable that the factors causing it would be indicated, uncomplicated by the presence of injurious impurities, uncombined arsenic or too loosely combined arsenic. In fact, such knowledge would provide a basis or standard with which to compare results obtained from the use of commercial materials. Accordingly, the attempt was made to obtain pure acid lead arsenate and pure neutral lead arsenate.

To get these seemed at first to be almost impossible. A number of manufacturers were willing to supply them, but the samples received proved on analysis to be far from pure, and nearly two years passed before materials were found so nearly pure that it was believed they would be satisfactory.[1]

Pure Acid Lead Arsenate Paste. — The material used in these experiments analyzed as follows: —

	Per Cent.
Water, H_2O	46.99
Water in combination and occlusion	1.33
Lead oxide, PbO	34.58
Arsenic pentoxide, As_2O_5	17.11
Chlorine, Cl	.04
Insoluble matter	.01
	100.06

The probable original composition of the paste, reconstructed from this analysis, was substantially as follows: —

	Per Cent.
Water, H_2O	46.99
Water occluded	.09
Acid lead arsenate, $PbHAsO_4$	47.87
Neutral lead arsenate, $Pb_3(AsO_4)_2$	4.93
Lead chloride, $PbCl_2$	.16
Insoluble matter	.01
	100.05

[1] See Holland and Reed: The Chemistry of Arsenical Insecticides, Twenty-fourth Annual Report, Mass. Agr. Exp. Station, Part I, pp. 180–182, 1912, for a fuller discussion.

The impurities present here — the lead chloride and insoluble matter — occur in such infinitesimal amounts and are of such a nature that they certainly could not cause any injury on foliage.

As the purpose of using this material was to test acid lead arsenate, the presence of nearly 5 per cent of the neutral salt was unfortunate; but, as will be shown in studying the results following the use of the neutral salt, its presence here would, if anything, tend to increase the safety of the spray rather than reduce it. The substance, then, was rather more than half arsenates of lead and rather less than half water.

This material, mixed with water at the rate of 1 part of the dry matter of the paste to 1,000 of water and kept twenty-four hours, gave .03 per cent of arsenic pentoxide (As_2O_5) as entering into solution during that time. As the Federal law permits .75 per cent of solubility under such conditions, it is evident that the sample was of excellent quality from this standpoint.

The rate at which lead arsenate settles when mixed with water is also an important factor, those brands which settle most slowly being distributed most evenly over the tree in spraying. This sample had completely settled eighty-one minutes after a thorough mixing, which is excellent for paste lead arsenates.

Commercial Lead Arsenate Paste. — This material, purchased from a dealer, was of a brand commonly used. Analyzed, it gave: —

	Per Cent.
Water, H_2O	46.32
Water in combination and occlusion	1.26
Lead oxide, PbO	35.44
Arsenic pentoxide, As_2O_5	16.29
Ferric and aluminum oxides	.19
Chlorine, Cl	.31
Nitric acid, HNO_3	trace
Insoluble matter	.04
	99.85

The probable original composition of this paste was substantially as follows: —

	Per Cent.
Water, H_2O	46.32
Water in occlusion	.19
Acid lead arsenate, $PbHAsO_4$	37.96
Neutral lead arsenate, $Pb_3(AsO_4)_2$	13.50
Iron and aluminum as ferric arsenate	.54
Lead chloride, $PbCl_2$	1.22
Nitric acid, HNO_3	trace
Insoluble matter	.04
	99.77

In this material less than 2 per cent could be termed impurities, and these were of such a nature as to make it practically certain they could

not cause any injurious effect on foliage. Rather more than half of the whole consisted of arsenates of lead, but the neutral salt formed a much greater part of the total than was the case with the pure material. About the same amount of water was present as in the pure substance. Or, the total amount of arsenate in the two did not differ greatly, but there was more than three times as much of the neutral arsenate in the commercial salt as in the pure one, the acid arsenate being correspondingly decreased. Any marked difference in the results following spraying by these materials, then, might possibly be explained by this difference in composition. In fact, the results did not differ greatly.

This paste, mixed with water as described for the pure paste, gave .09 per cent of arsenic pentoxide as entering solution in twenty-four hours. This, though more than with the pure paste, is also far below the amount permitted by the Federal law. Complete settling after mixing with water required only thirty-four minutes, showing that this commercial material was rather poor in this regard as compared with the pure paste.

Commercial Acid Lead Arsenate Powder. — The appearance on the market during the progress of these experiments of lead arsenate in powder form led to the addition of this material to the list of substances to be investigated. Samples from a brand on sale were obtained, analyzed and tested like the others. The analysis gave: —

	Per Cent.
Water, H_2O	.45
Water in combination and occluded	3.20
Lead oxide, PbO	63.25
Arsenic pentoxide, As_2O_5	32.22
Ferric and aluminum oxides	.40
Insoluble matter	.38
	99.90

From this the original composition of the powder was probably substantially as follows: —

	Per Cent.
Water, H_2O	.45
Water in combination and occluded	.68
Acid lead arsenate, $PbHAsO_4$	89.93
Neutral lead arsenate, $Pb_3(AsO_4)_2$	7.28
Iron and aluminum as ferric arsenate	1.16
Insoluble matter	.38
	99.88

This material as used for spraying, therefore, contained a little more than 1 per cent of water, about 90 per cent of acid lead arsenate, rather more than 7 per cent of neutral lead arsenate, and about 1½ per cent of impurities, none of them of a nature or present in sufficient amount to be liable to cause any injury.

The amount of arsenic pentoxide which had entered into solution after twenty-four hours of treatment was .16 per cent, which, though more than with either of the other materials already considered, was still far below

that permitted by the Federal law. The time required for the powder to settle was 255+ minutes, which places this sample far ahead of either of the pastes in this regard.

Pure Neutral Lead Arsenate Paste. — This material has been highly recommended as being safer on foliage than the acid lead arsenates, and an investigation of it was therefore also made. To obtain it in a pure or nearly pure form was very difficult, however,[1] and the best sample obtainable analyzed as follows: —

	Per Cent.
Water, H_2O	70.97
Water in combination (calculated)	.08
Lead oxide, PbO	21.10
Arsenic pentoxide, As_2O_5	7.33
Acetic anhydride, $C_4H_6O_3$	.10
Sodium oxide (calculated to combine with last)	.06
Carbonic acid, CO_2	.15
Insoluble matter	.01
	99.80

The original composition of this sample was therefore substantially as follows: —

	Per Cent.
Water, H_2O	70.97
Water occluded	–
Acid lead arsenate, $PbHAsO_4$	3.14
Neutral lead arsenate, $Pb_3(AsO_4)_2$	24.61
Lead carbonate, $PbCO_3$	.91
Sodium acetate, $NaC_2H_3O_2$	.16
Insoluble matter	.01
	99.80

This sample contained a very large amount (71 per cent) of water, was nearly one-quarter neutral lead arsenate, and contained a little over 3 per cent of acid lead arsenate and rather more than 1 per cent of impurities of such a nature as to indicate that it had not been sufficiently washed to remove all the acetic acid, and that impure sodium arsenate containing some carbonate had been used from which to obtain the arsenic. None of these materials was apparently present in sufficient amount to cause any foliage injury, — a view sustained by the results later.

The solubility of the sample in water was .07 per cent on standing twenty-four hours, and it required an hour for complete settling.

None of the materials showed on analysis the presence of impurities of such kinds and in such amounts as to make injury to the foliage from this cause at all probable.

As a commercial neutral lead arsenate could not be obtained which did not contain a large amount of the acid arsenate also, tests of such a material were not made.

[1] See Holland and Reed, *loc. cit.*, p. 203.

Application.

The trees used were the apple, cherry, peach, pear, plum and elm. The materials were applied in the same way in all cases, being thoroughly mixed with the proper amount of water just before using. With the acid pastes, 3 pounds in 50 gallons of water, and with the powder, $1\frac{1}{2}$ pounds, were used, the powder containing approximately twice as much arsenic pentoxide as the pastes. As the neutral arsenate contained much less pentoxide than the acid pastes, 5 pounds 7.6 ounces of it were mixed with 50 gallons of water to provide an amount of arsenic pentoxide in the spray equal to that present in the others. Practically an equal amount of poison was therefore applied in every case.

It has been suggested that injury might be caused by the poison entering the leaf through the stomata. As these are usually more numerous on the lower than on the upper surface, branches were held by the hand in such a position that the spray would reach only one surface of the leaf. Parallel tests for both surfaces were made, one test immediately following the other and on the same tree. The main lines of investigation, though, were with reference to variations of temperature and humidity and of light. Two series were made, one in bright, clear weather, and the other on cloudy days.

The temperature and humidity were obtained from a Hygrodeik manufactured by Andrew J. Lloyd & Co. of Boston, giving both the temperature and relative humidity. These were taken at the tree immediately before applying each spray. The attempt was made to spray each surface of the leaves, both in clear and cloudy weather, for at least every 5° interval between 65° and 95° of temperature, and between 50° and 90° of humidity. To obtain all these combinations, however, proved difficult, and some of them were not obtained until several years had elapsed, though fairly complete series were finally secured.

Application of the sprays was begun in June, continued during July, and a few sprays were put on the trees early in August. The tests were begun in 1912 and ended in 1920. After the spray had been applied, its effect was observed about twice a week for at least two weeks, so that any injury appearing late might not be overlooked.

Adequacy of Experimental Methods.

Three possible sources of error, at least, may have affected this experiment. First, there is the difficulty of a uniform estimation of the amount of injury found. As a check upon this we have the very uniform agreement in observations made at identical and nearly identical temperatures and humidities, not only in the same, but also in different years. The personal equation was reduced as much as possible by having the observations all made by one person. Then, after all, the main dividing line was between injury and no injury, determination of the exact degree of injury being of less importance.

A second source of error was the necessity of using different varieties of the fruit trees, in some cases, in different seasons. If different varieties of the same kind vary in their degree of resistance, the results might be expected to vary also, to some extent. This could not hold for the plum, all tests with this being of the Bradshaw variety, and for the elm, which was always the American elm. With the other trees the results do not indicate, at least, that varietal difference was a factor, though it is generally believed that the Baldwin, for example, burns more easily than the McIntosh. How much the results of these experiments were affected by varietal differences cannot be determined.

The third source of error is the possibility of a difference in the leaves as the season progresses, the later sprays having, perhaps, been applied to leaves which had already begun to "harden." Here, too, the results fail to indicate that this was a factor. Burning occurred as frequently after the late July and early August sprays as following the earlier ones, under similar conditions of temperature and humidity, and it would seem that this possible source of error was of little if any importance.

General Results.

Some general conclusions from the investigation were: —

1. The difference in sensitiveness between the upper and under surfaces of the leaves is so slight as to be negligible. Not more than a dozen cases of difference were observed out of nearly 1,600 applications. In these few the under surface showed the greater injury. Apparently in cases of spray injury, it is not caused by the poison entering the leaf through the stomata.

2. Where insects or fungi had produced holes in the leaves, spray injury was frequently observed around the edges of these holes, while the rest of the leaf was not affected. Whether this injury resulted from a freer access of the poison to the inner leaf cells, or would have resulted in any case, is perhaps uncertain. Such injury was not rated as injury by spraying where the unattacked remainder was not affected.

3. It was frequently the case that injury did not appear until nearly a week after spraying (longer in some cases), and increased in severity later. A branch graded as showing a trace of injury at the end of the first week often increased to "slight" after two or three days, and even to "bad," in a few cases, by the end of the second week. In general, though, the final degree of injury had been reached after about twelve or thirteen days.

4. It is well known that some kinds of foliage are more sensitive to arsenical sprays than others, but details as to this have hitherto been lacking. These tests show that the pear and elm are the most resistant of the trees used in the experiments; that the apple comes next, but is much less resistant; that the cherry comes considerably below the apple in this regard; and that the Bradshaw plum and the peach come some distance below the cherry, and are about equally sensitive, the peach being probably rather the more sensitive of the two.

5. No injury either from the pure or commercial materials was obtained with a combination of the lower temperatures and humidities, but traces of it began to appear as these factors became higher. This indicates that one or both of these affect the leaf in some way so that it becomes more sensitive the higher either one goes, and also that medium high temperatures and medium high humidities act together. The results of this work show that with reasonably good materials injury caused is determined by temperature, humidity and perhaps light. The effects of these are therefore given in greater detail below.

The Effects of Temperature, Humidity and Light.

Pear and Elm. — No case of injury to either of these trees was produced by any of the sprays, even at the highest combinations of temperature and humidity (hereafter written T and H) obtained in the course of the work. It may be remarked, however, that this was not true with Paris green and calcium arsenate, the results with which are not included in this bulletin, both materials seriously injuring the leaves under certain T and H combinations. Combinations as high as T91 H71, T80 H84, and T84 H82 resulted in no injury from lead arsenate, and the conclusion is reached that under any usual combinations of T and H obtainable during the summer months, spraying these trees with any reliable brand of lead arsenate should be entirely safe.

Apple. — Fig. 1 shows the results obtained by using pure acid lead arsenate paste in clear weather. The dots show the T and H points obtained for each test; a circle around the dot indicates that there was no injury; *t* indicates a trace of injury, and *s* indicates slight or "some" injury. Figures in parentheses give the number of tests at the same T and H. A line AB can be drawn across the chart somewhat below the *t* spots, which may be termed the safety line under the conditions of this test. Spraying above the TH limits of this line may not result in injury, as four cases on the chart show, but neither can safety be assured above the line.

Fig. 2 shows the results obtained with the same material applied in cloudy weather. It will be noticed that the lowest humidity was 68°, and that only one high temperature (91°) was met with under the required conditions during the six years the tests were carried on. Apparently, cloudy weather is hardly possible (as is to be expected) with low humidities, and also high temperature tends to dissipate clouds.

So far as can be judged from these tests, there is little real difference in results between clear and cloudy weather, except perhaps at the high humidity end of the safety lines. It would seem that injury begins a little sooner in cloudy than in clear weather at medium T and H, but only slightly so with low T. This is made evident by Fig. 3, where the safety lines only are shown together. Here the cloudy weather line diverges from the other toward the high H end of the diagram, though, after all, only by about 5° at H90.

APPLE — RESULTS OF SPRAYING WITH PURE ACID LEAD ARSENATE.

AB, safety line.

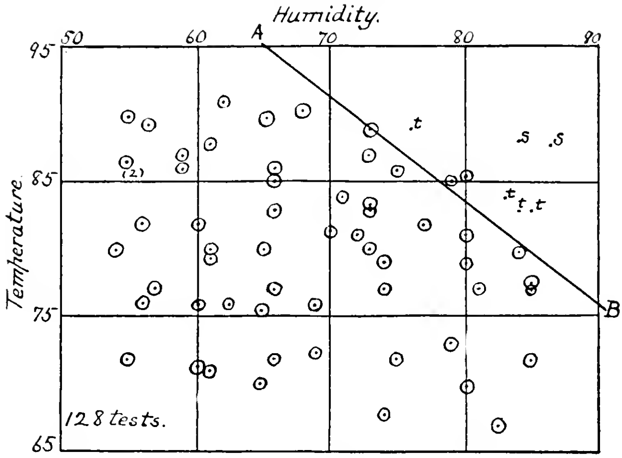


FIG. 1. — Clear weather.

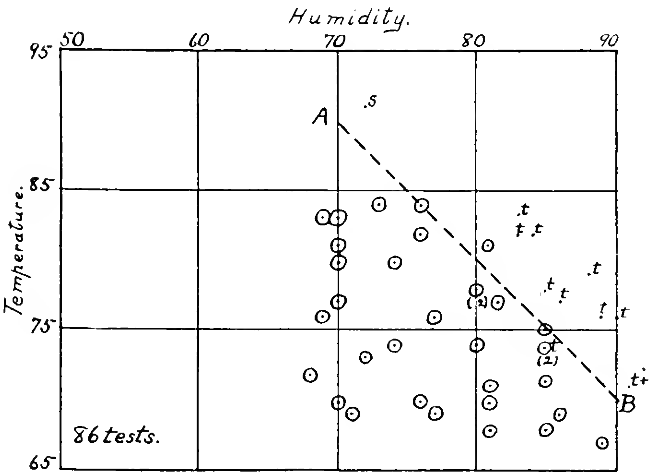


FIG. 2. — Cloudy weather.

With commercial lead arsenate paste the results as shown in Fig. 4 are much the same, though on the whole injury occurs before T and H get quite as high as with the pure paste, particularly at the higher humidities. The clear and cloudy weather lines are more nearly parallel than in the other case.

APPLE — SAFETY LINES FOR SPRAYING.

AB, clear weather; CD, cloudy weather.

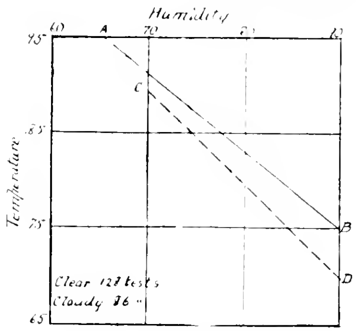


FIG. 3. — Pure acid lead arsenate paste.

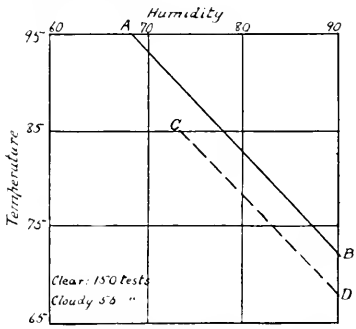


FIG. 4. — Commercial acid lead arsenate paste.

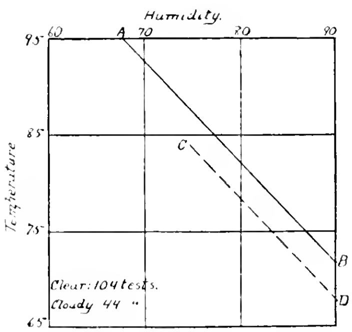


FIG. 5. — Commercial acid lead arsenate powder.

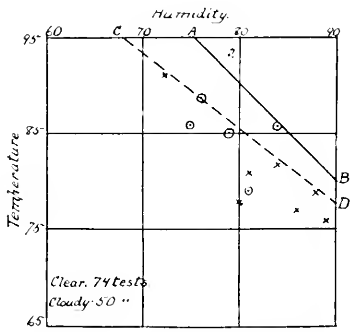


FIG. 6. — Pure neutral lead arsenate paste. Crosses indicate cloudy weather tests with no injury; circles, clear weather tests with no injury.

In the case of commercial lead arsenate powder (Fig. 5), the results differ somewhat, the clear weather safety line beginning at a higher H than in the other cases, but crossing these and running out on H90 at a lower temperature. The total difference, however, is only 4°, so that, after all, there is no great significance in this. The cloudy weather line nearly parallels the clear weather one, and runs about 1° above the commercial paste cloudy weather line.

Results from the use of neutral lead arsenate were rather different from those following the other lead arsenates, this material being apparently the safest of those used. No injury except one doubtful case was found, either

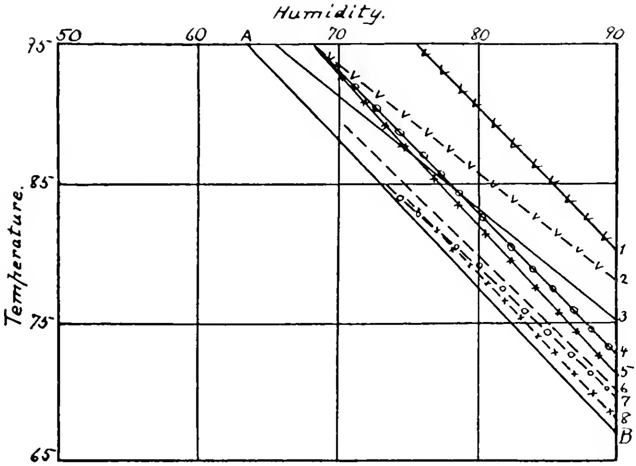


FIG. 7. — APPLE — SAFETY LINES FOR ALL LEAD ARSENATES. AB, safety line for spraying with any reliable lead arsenate under all weather conditions; 1, neutral lead arsenate, clear weather; 2, same, cloudy weather; 3, pure acid paste, clear weather; 4, commercial acid paste, clear weather; 5, commercial acid powder, clear weather; 6, pure acid paste, cloudy weather; 7, commercial acid paste, cloudy weather; 8, commercial acid powder, cloudy weather.

in clear or cloudy weather, at the combinations of T and H obtained, and the safety lines were finally placed near the highest records taken. Fig. 6 shows these records and the placing of the safety line with reference to them. So far as can be judged, then, this material is safe to apply under any ordinary combinations of T and H up to the line AB of Fig. 6.

A general conclusion on the apple is that apple foliage is quite resistant to lead arsenate at high temperatures if the humidity is low, and at high humidities if the temperature is low. Thus, spraying appears to be safe at T90 or higher if the H is below 66. With intermediate T and H, however, the two appear to combine, so that at T82, for example, H should not be above 76.

Cherry. — The cherry appears to be much less resistant to injury than the apple. Fig. 8 gives the safety lines for clear and cloudy weather with pure acid lead arsenate paste. Comparing this figure with Fig. 3, we see that temperature is a more active agent with the cherry than the apple, and that this is even more marked in cloudy weather, though with less difference at low temperatures and high humidity.

CHERRY — SAFETY LINES FOR SPRAYING.

AB, clear weather; CD, cloudy weather.

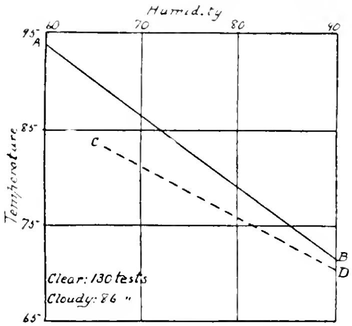


FIG. 8. — Pure acid lead arsenate paste.

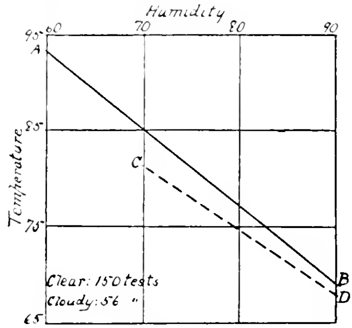


FIG. 9. — Commercial acid lead arsenate paste.

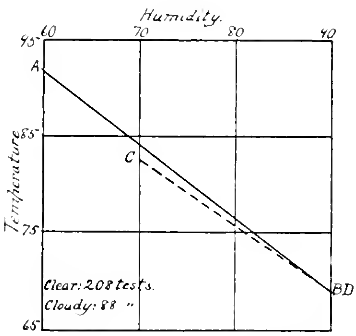


FIG. 10. — Commercial acid lead arsenate powder.

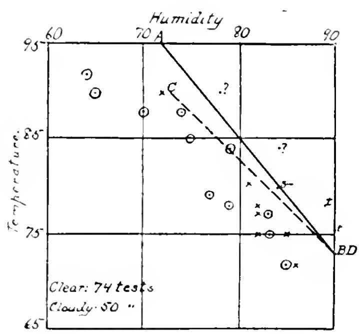


FIG. 11. — Pure neutral lead arsenate paste. Crosses indicate cloudy weather tests with no injury; circles, clear weather tests with no injury.

With commercial acid lead arsenate paste (Fig. 9) the safety lines are very similar to those given in Fig. 8, though a little lower. The difference is insignificant, however. With the commercial acid lead arsenate powder (Fig. 10) the results are also similar, but there seems to be less difference between clear and cloudy weather in producing injury.

The tests with the neutral lead arsenate paste support those on the apple in indicating higher T and H as necessary to cause burning. In Fig. 11 a few of the actual tests are recorded, those marked by circles being clear weather tests and those by crosses, cloudy weather ones. The two interrogation mark tests were clear weather tests, and whether they were really spray injuries is at least doubtful. The two marked "t" and the "s" were cloudy weather tests.

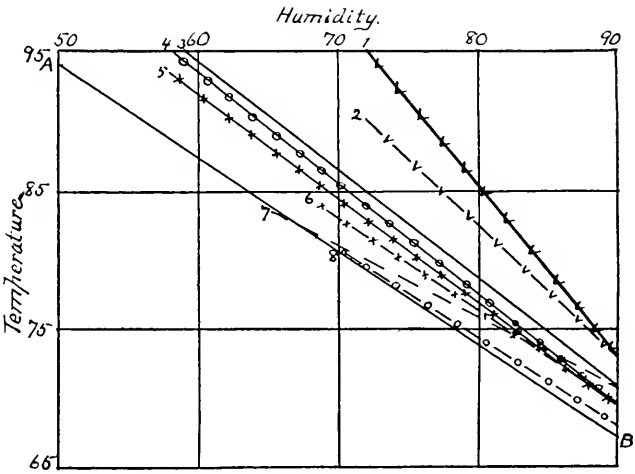


FIG. 12. — CHERRY — SAFETY LINES FOR ALL LEAD ARSENATES. AB, safety line for spraying with any reliable lead arsenate under all weather conditions; 1, neutral lead arsenate, clear weather; 2, same, cloudy weather; 3, pure acid paste, clear weather; 4, commercial acid paste, clear weather; 5, commercial acid powder, clear weather; 6, same, cloudy weather; 7, pure acid paste, cloudy weather; 8, commercial acid paste, cloudy weather.

A combination of all the safety lines is given in Fig. 12. The convergence of the lines, in many cases almost to a common point, produces a rather confusing diagram, the significant features being the detached position of the neutral arsenate (1 and 2), the practical parallelism of the other materials in clear weather, and the fact that these are all located at higher H than the same materials in cloudy weather. The arbitrarily placed line AB may be regarded as the safety line for the cherry with any reliable lead arsenate, either in clear or cloudy weather.

A general study of the results obtained by spraying the cherry indicates that this tree is more sensitive to high temperatures where H is low than the apple, while at high humidity with low T it is, on the whole, more resistant. In both fruits the general agreement in each case of the various acid pastes and the noticeable way in which the neutral arsenate stands apart from the others are very marked.

PLUM — SAFETY LINES FOR SPRAYING.

AB, clear weather; CD, cloudy weather.

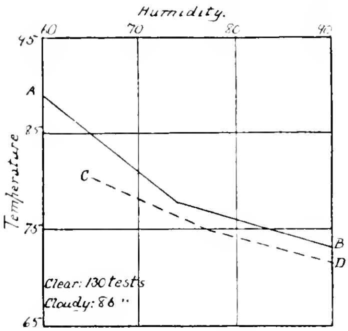


FIG. 13. — Pure acid lead arsenate paste.

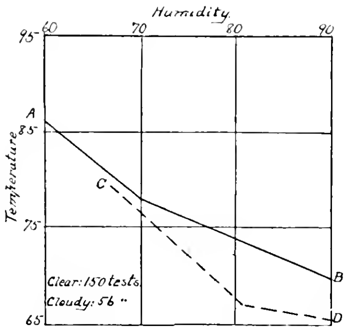


FIG. 14. — Commercial acid lead arsenate paste.

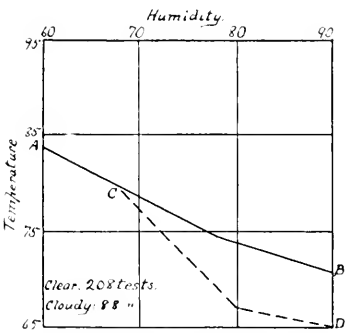


FIG. 15. — Commercial acid lead arsenate powder.

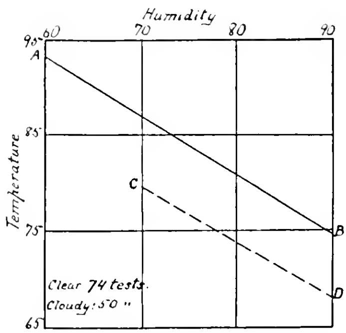


FIG. 16. — Pure neutral lead arsenate paste.

Plum. — The facts obtained here apply only to the Bradshaw plum. The results of the tests of pure acid lead arsenate paste in clear and cloudy weather are given in Fig. 13, and show at once that the resistance of this tree to arsenical sprays is much less than that of the cherry. An addi-

tional feature, here first met with in the work, is the fact that the safety lines are not straight but "elbowed." It would seem from the evidence available that in the case of the plum a combination of medium high T and H becomes dangerous more quickly as these increase than with the cherry or apple. This "elbow" is also shown in Fig. 14 giving the safety lines with the commercial paste. Here the lines run on lower T and H, and in cloudy weather humidities above 80, even with low T, are dangerous. A somewhat similar result following the use of the powder is given in Fig. 15 in the case of cloudy weather. The clear weather results differ only slightly from those with the paste.

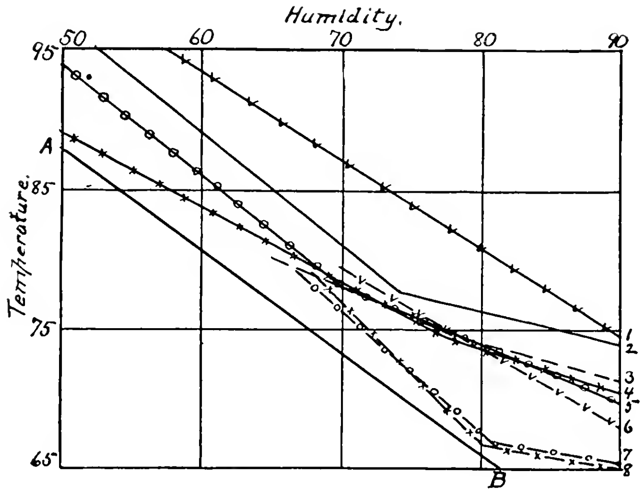


FIG. 17. — PLUM — SAFETY LINE FOR ALL LEAD ARSENATES. AB, safety line for spraying with any reliable lead arsenate under all weather conditions; 1, neutral lead arsenate, clear weather; 2, pure acid paste, clear weather; 3, same, cloudy weather; 4, commercial acid powder, clear weather; 5, commercial acid paste, clear weather; 6, neutral lead arsenate, cloudy weather; 7, commercial acid paste, cloudy weather; 8, commercial acid powder, cloudy weather.

The neutral arsenate, as in the case of the other trees, is much safer than the acid arsenates, though the cloudy weather line (Fig. 16) for the first time drops to run about along with those of the acid pastes in clear weather. No "elbow" appears for the neutral arsenate.

In Fig. 17 the various safety lines are brought together on one chart. The striking point shown here is that in the high humidities of cloudy weather the commercial paste and powder, closely following each other, drop far below the other lines. On the whole, the line AB should mark a safety line, however, at or below which spraying on the plum should be safe under any combinations of T and H with any reliable material.

General conclusions as to the plum, so far as the evidence goes, are: first, that this tree is far less resistant to arsenicals under certain conditions of T and H than the cherry; second, that in clear weather it is less sensitive to high humidities than to high temperatures when the other factor is low; third, that this last does not hold for the acid paste and powder in cloudy weather; and fourth, that again the neutral lead arsenate is the safest of the materials used.

PEACH — SAFETY LINES FOR SPRAYING.

AB, clear weather; CD, cloudy weather.

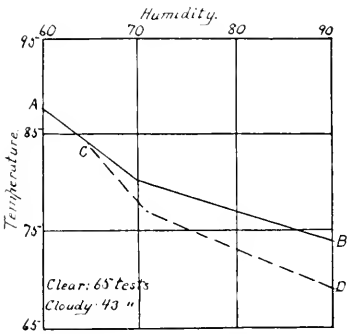


FIG. 18. — Pure acid lead arsenate paste.

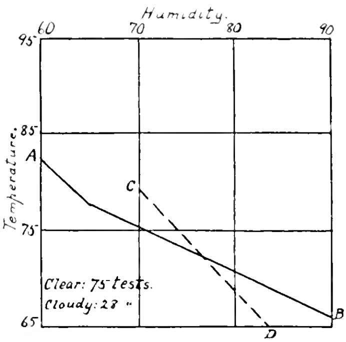


FIG. 19. — Commercial acid lead arsenate paste.

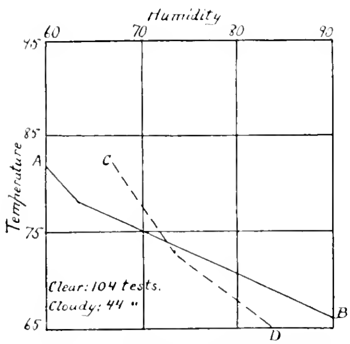


FIG. 20. — Commercial acid lead arsenate powder.

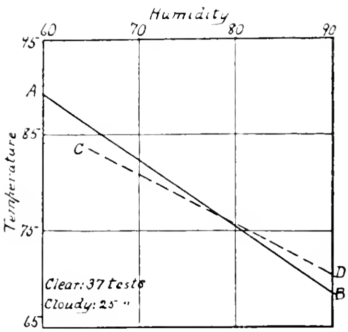


FIG. 21. — Pure neutral lead arsenate paste.

Peach. — The results of the experiments on the peach are, on the whole, very similar to those obtained from the plum. In general, the safety lines are very close, and the conclusion reached that the plum is somewhat more resistant than the peach is based mainly upon experiments with other arsenicals. There seems to be less difference at the T and H limits of the charts than was shown for the plum. In three sets of tests (Figs. 19, 20 and 21) the clear and cloudy weather lines cross, but the difference is not very great. The neutral arsenate fails to make quite as good a showing as with

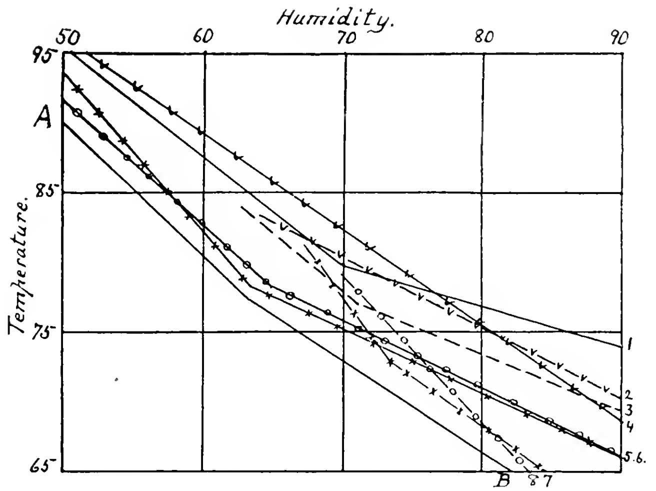


FIG. 22. — PEACH — SAFETY LINES FOR ALL LEAD ARSENATES. AB, safety line for spraying with any reliable lead arsenate under all weather conditions; 1, pure acid paste, clear weather; 2, neutral lead arsenate, cloudy weather; 3, pure acid paste, cloudy weather; 4, neutral lead arsenate, clear weather; 5, commercial acid paste, clear weather; 6, commercial acid powder, clear weather; 7, same, cloudy weather; 8, commercial acid paste, cloudy weather.

the other trees, but is, nevertheless, still the best for the greater part of its range. "Elbowing" of the safety lines is again in evidence except with the neutral arsenate and the commercial acid paste in cloudy weather. Perhaps in this last case a larger number of tests (it was not possible to make very many) might change the path of this line somewhat. Comparison of Figs. 17 and 22 shows that the peach appears to resist injury slightly better than the plum at high T and low H, while at high H and low T the two are about alike.

It should be noted that in Figs. 7, 12, 17, 22 and 23 the chart is extended 10° lower in humidity than the others to show the paths of the safety lines in this added area. To make comparisons with the others, reading of these charts should begin, not at H50, but at H60.

In order to obtain some idea of the relative resistance of the apple, cherry, plum and peach to arsenical sprays, Fig. 23 has been prepared, the material used in each case being the pure acid lead arsenate paste applied in clear weather. The elm and pear are not included, for as already stated, no injury points were obtained. If their safety lines come into the chart at all, they would only cross the upper right square, and probably would not occur unless close to H90 T95.

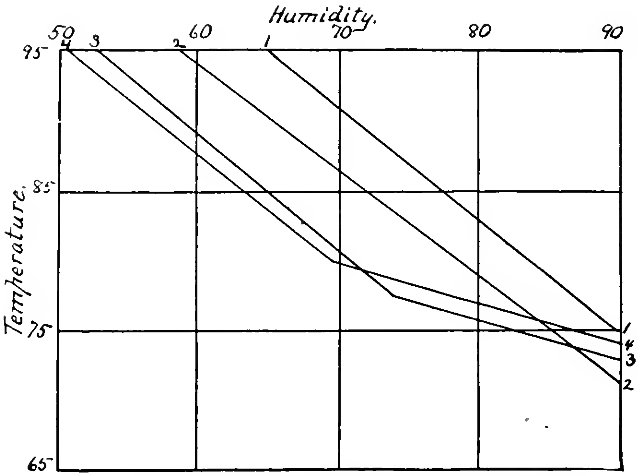


FIG. 23. — Safety lines for spraying with pure acid lead arsenate in clear weather: 1, apple; 2, cherry; 3, plum; 4, peach.

GENERAL CONCLUSIONS.

An analysis of the effects of temperature, humidity and light given in detail above brings out several features of interest: —

1. The neutral lead arsenate used, even though it was not entirely pure, proved the safest of the materials in clear weather, and in most cases was better even in cloudy weather than the others.

2. The clear weather spraying is safer than the cloudy weather, though the difference generally is not great.

3. The indication is that spraying at high temperatures can be done safely if the humidity is low.

4. Spraying can be carried out safely at high humidities if the temperature is low, though the humidity cannot run up as high as the temperature can at the other end of the line. Thus spraying the apple seems to be safe at T90 when H is not over 69, but is not safe at H90 when T is above 67.

5. Between the ends of the safety lines of the charts, *i.e.*, with medium T and H, both seem to have an influence.

6. With the apple and cherry the safety lines are straight, while in the plum and peach most of them "elbow," indicating that the T and H fac-

tors are more powerful at medium values, or when both act in medium amounts, than where either one is low, even though the other be high.

7. In the case of the plum the elbow is between H70 and H80, while with the peach it tends to move back toward lower humidities; or, in other words, the plum seems to be more sensitive to higher humidities than the peach, and also at the extremes of the safety lines to both T and H.

8. From the tests with lead arsenate, the peach and the Bradshaw plum at least appear to have about the same degree of resistance to arsenical sprays.

From the evidence at hand it would seem that, with reliable arsenicals properly made, mixed and applied, injury results from the combination of temperature, humidity and light factors. A high value for either of the first two factors, provided the other is low, indicates probable safety, particularly on sunny days.

Why divergence from these requirements should cause burning has not been brought out by this work. It may be that, as the injury generally appeared only after a week or more, there was some chemical factor at work. With some carbonic acid in the air and heavy dews at night it might be possible that a slow decomposition of the arsenate on the leaves took place, gradually liberating the arsenic and resulting after a time in injury. If this were correct, however, it would seem as though the decomposition of the arsenate would take place when sprays were applied at T and H combinations below the safety line, and cause burning in those cases also. Possibly the leaf differs in its physiological activities under different conditions of light, temperature and humidity, and under some of these is susceptible to influences not effective under others.

The most that can now be said is that this work has failed to answer the question why arsenical sprays sometimes injure foliage, though it has shown that of the four explanations given at the beginning, the first, second and fourth can be rejected, and that the problem is apparently one for the plant physiologist, the chemist, or both working together, to solve. The demonstration of safety limits for spraying can hold good, however, even though the question of why they are located where they are remains unanswered.

BULLETIN No. 208.

DEPARTMENT OF POMOLOGY.

LEAF CHARACTERS OF APPLE VARIETIES.

BY J. K. SHAW.

It is as easy to recognize varieties of apples by their tree characters as by their fruit, yet all fruit growers know varieties by the fruits much better than by the trees. This is doubtless because they come into closer contact with the fruit. They pick, handle and eat the fruit, while contact with the trees is less frequent and intimate. Nurserymen are more familiar with the tree, and many old nurserymen know varieties by the nursery trees better than by the fruit. As trees have been studied less than the fruit, there has been less written about them. Variety descriptions deal mostly with the fruit. John J. Thomas, himself a nurseryman of many years' experience, discussed tree characters at some length in his "American Fruit Culturist," but his work along this line has been given little attention by other writers.

In recognizing varieties, especially with nursery trees, one depends largely on the leaves, and it is our purpose here to discuss the leaf characters by which we may know one variety from another. Characters of the bark, buds, branches and general habit of the trees are very useful, perhaps equal to the leaves, but they will receive only incidental mention here, being reserved for further study and later discussion.

In order to talk understandingly about the leaves we must have names for their different parts. These are shown in Fig. 1, which is largely self-explanatory. The leaf is first divided into three parts: stipules, petiole and blade. About one-third of the blade next to the petiole is called the base, and similarly about one-third of the other end, the apex; beyond this is the narrow point called the tip. The midrib is a continuation of the petiole to the tip of the leaf. The saw-like notches along the edge of the leaf are called serratures or serrations, and are of the greatest importance, being rarely exactly alike in two varieties.

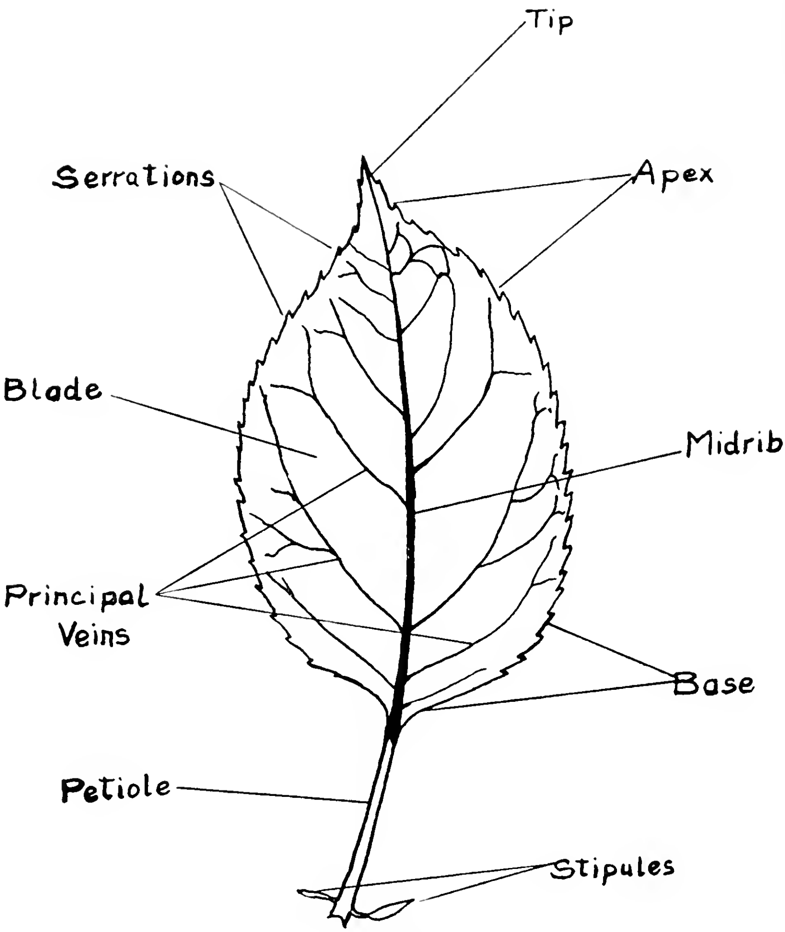


FIG. 1. — Diagram of apple leaf, showing parts.

Which are the Characteristic Leaves.

The leaves on any tree can be divided into two groups: (1) the single leaves coming out on the current season's growth; and (2) the rosette leaves coming out of buds formed the previous season, *i.e.*, on wood of last year's growth. *The latter should be discarded, and study and attention centered on the single leaves on the current season's growth.* Leaves that have been injured by lice or other insects or by scab spots are of little value for identification purposes. Leaves on shoots in the interior of the tree should be avoided. *Study the well-developed uninjured leaves usually found along the middle of the season's growth.* Leaves on trees that are poorly nourished are often undersized and yellowish. Such leaves are not typical and should be observed with caution.

Typical leaves are found on healthy uninjured trees that are making vigorous but not excessive growth. Inasmuch as one requires the leaves of the current season's growth, little progress can be made in leaf study until considerable growth has been made. The most favorable period is from July 1 until October 1. To one familiar with leaf characters this period may be extended somewhat.

What to Look at.

To the beginner in leaf study the leaves of all varieties will look alike. Close and repeated observation will reveal differences that are peculiar to the different varieties. It is our purpose here to discuss the various parts of the leaf and how they differ in different varieties. (See Fig. 1.)

The Petiole.

The petiole or stem of the leaf is sometimes characteristic of the variety, though it is of minor importance. Wealthy has a rather long, slender petiole, while that of McIntosh is usually short and stout. The angle which the petiole forms with the shoot on which it grows is often helpful in recognizing varieties. In the Spy the angle is sharp, that is, the leaf is said to be upright; while in the Rhode Island Greening it is broad or spreading. This character is correlated in all varieties with the form of the top. The Spy has an upright head, while the Rhode Island Greening is distinctly spreading. This character of the head or form of the tree is quite well known to fruit growers, but few are aware that in an unknown variety the form of the top can be foretold with considerable accuracy from the leaf angles on a one-year whip.

The Stipules.

The stipules located at the base of the petiole have a certain value in variety identification. They vary in size and shape and in the degree to which they persist. In all or nearly all varieties they are likely to fall by late summer or early fall, especially if there is a good deal of dry weather.

The Blade.

Size. — Coming now to the blade we find the most dependable characters for variety identification. Let us first consider the size of the leaf blade. This, of course, varies considerably with the vigor of the tree. Trees in a sod orchard making little growth will have much smaller leaves than will the same variety growing under cultivation and making a vigorous growth. Leaves well exposed to the sun will be smaller than those growing in shade, as in the interior of the tree. With these reservations in mind, we may say the Jonathan (Fig. 17) has a small leaf, while Rhode Island Greening (Fig. 4) and King (Fig. 24) have large leaves; Wealthy (Fig. 7) is a little smaller than Baldwin (Fig. 8); and McIntosh (Fig. 3) a little larger than Wolf River (Fig. 12).

Shape. — Next we may consider the shape or outline of the leaf. This may vary in different varieties in two ways: in relative length and width, and in the width of the base and apex. Winter Banana (Fig. 10) is relatively long and narrow, while Baldwin (Fig. 8) is relatively short and broad. An example of the second is found in comparing Wolf River (Fig. 12), which is narrow at the base and apex, with McIntosh (Fig. 3), which is broad at the base and apex. This difference is especially valuable in distinguishing between Oldenburg (Fig. 6) and Wealthy (Fig. 7), the former being much broader at the base and apex than the latter.

Tip. — The narrow tip called the point is of some value, being larger and more slender in some varieties, usually those with a narrow apex, than in others.

Folding. — Next we may consider the various types of bending and folding which may appear in the leaf blade. The blade may be flat as in Gravenstein (Fig. 2) and Wealthy (Fig. 7), or it may be folded to a greater or less degree as in Baldwin (Fig. 8) or Wagener (Fig. 15). The last two varieties exhibit different types of folding, it being broad, saucer-shaped or boat-shaped in the Baldwin, and much narrower and more pronounced in the Wagener. Leaves of a given variety may show this character in varying degree according to condition; the folding is more pronounced in periods of dry, sunny weather than it is during cloudy or rainy periods. Jonathan, as shown in Fig. 17, shows only moderate folding, but at times it may show very pronounced folding, — sometimes more than any variety illustrated here. Nevertheless, it is a most valuable character in the identification of varieties. The peculiar saucer-shaped folding of the Baldwin is always seen in greater or less degree in a considerable proportion of the single leaves on the tree, and with one or two other peculiarities will serve to distinguish this variety from all others.

Next we may consider the bending or waving of the leaf edge. Flat leaves do not often show this, although it appears quite noticeably in Oldenburg and Wealthy, neither of which are folded very much. Some folded leaves are very distinctly waved, as Wagener (Fig. 15), Hubbardston (Fig. 22) and Tolman (Fig. 27), while others show it but little, as Baldwin (Fig. 8), Roxbury Russet (Fig. 9) and Winter Banana (Fig. 10).

A third type of bending or folding of the leaf blade is seen in the bending backward or reflexion of the midrib. Pronounced reflexion of the midrib is not common in flat leaves, but is the usual thing in strongly folded leaves if the folding is of the narrow type. Thus Baldwin (Fig. 8) and Roxbury Russet (Fig. 9) are not reflexed, while Grimes (Fig. 20) and Wagener (Fig. 15) are strongly reflexed.

Serratures. — Probably the most dependable leaf character for identifying varieties is the nature of the serratures along the edge of the leaf. They are sharp in Rhode Island Greening (Fig. 4) and dull in Wolf River (Fig. 12) and Wealthy (Fig. 7). Other varieties are intermediate between these extremes, but every variety is peculiar to itself and different from other varieties. In Rhode Island Greening (Fig. 4) the serratures are distinct or well separated, while in Gravenstein (Fig. 2) and Baldwin (Fig. 8) they are set close together or indistinct. They vary in depth also, and in some varieties they are straight, as in Rhode Island Greening, while in Baldwin they are more or less curved or sickle-shaped. The last peculiarity, together with the saucer-shaped folding referred to above, serves to distinguish Baldwin from all other varieties known to the writer. If one leaf is laid upon another so that the serratures of both can be seen and carefully compared, the observer with some experience can very often tell quite positively whether the leaves represent one variety or two varieties.

Texture. — The veins of the leaves divide and subdivide until they form a network all over the surface of the leaves. This network is coarser in some varieties than in others. There are other peculiarities in the veining hard to describe in words, but evident and distinct in the leaves. These peculiarities taken together are spoken of as texture. The texture of Rhode Island Greening (Fig. 4) is very different from that of McIntosh (Fig. 3). Comparisons of other varieties will show differences in texture difficult to picture in words, but of much value in recognizing varieties.

Pubescence. — All varieties have more or less growth of short hairs over the under surface. Those having an abundant growth of these hairs are said to be pubescent or "woolly." This is not shown very clearly in the figures, but may be seen by observing the leaves themselves. Ben Davis and Jonathan are examples of "woolly" leaves, while Rhode Island Greening shows very little of this growth. This hairy growth is sparse on Baldwin and more abundant on Hubbardston and McIntosh.

In some varieties the surface of the leaves is smooth and shining, while at the other extreme are some varieties that appear rough or dull. This is correlated with hairiness or woolliness of the surface, the smooth and shining leaves having few hairs, while the rough or dull ones have many.

Thickness. — Varieties differ also in the thickness of the leaves. McIntosh and Wealthy have relatively thick, stiff, rigid leaves, while those of Rhode Island Greening, Grimes and Fall Pippin seem thinner and less rigid to the touch.

Color. — All apple leaves are, of course, a deep rich green in color. The shade of green depends a good deal on the vigor of the trees, being deeper in vigorous trees, and a paler, more yellowish green in trees making little

growth. There are also varietal differences in color. In Rhode Island Greening and in all green-fruited varieties the color is a rich, clear green; in varieties that have much red in the color of the fruit the leaves are a deeper green with a slight bluish or purplish cast. This is seen in McIntosh. Yellow Transparent has leaves of a yellowish green cast. These differences in leaf color are not pronounced, and as stated above vary with the condition of the trees, but they are very helpful in recognizing varieties.

In distinguishing two or more varieties which are mixed in the nursery row, one may often find some peculiarity of a certain variety present at the particular time at which the observation is made, which serves to distinguish that variety with ease and certainty. For example, in separating out Wolf River trees in a mixture with McIntosh it was observed that, at the time the Wolf River leaves were beginning to turn yellow and perhaps one-third of them had fallen, the McIntosh leaves showed very little yellowing and few if any had fallen. By observing this difference it was possible to separate the two varieties with the greatest ease and certainty. Yet at an earlier period this difference would not have been present. In the late summer the Yellow Transparent leaves near the tips of the shoots frequently show a spiral folding that displays plainly the under side of a portion of the leaf. When this peculiarity is shown it is possible to recognize a Yellow Transparent tree as far as it can be seen. It is the usual thing in separating mixed varieties to fix on some one character by which the varieties can, at that particular time and place, be positively distinguished one from the other.

Classification of Varieties.

Twenty-six varieties of more or less importance in Massachusetts have been selected for illustration and description in this bulletin. The following key is arranged to show, as well as possible, the differences by which these varieties may be distinguished. It is not thought that this key will enable one to trace out unknown varieties, but it may help in orchard and nursery studies of the leaves of these varieties. A few tree characters are mentioned with the hope that they may be helpful.

A. Varieties important in Massachusetts.
- 1. Leaves large, broad, flat or only slightly folded.
  - (*a*) Sides not waved or only very slightly so.
    - *Gravenstein.* — Leaves broad oblong; serrations dull, shallow, regular; branches broadly ascending; bark dark yellowish. (Fig. 2.)
    - *McIntosh.* — Leaves broad oval, base often cordate, edges often slightly folded; serrations dull and shallow, especially at base. (Fig. 3.)
    - *Rhode Island Greening.* — Serrations very sharp and distinct. (Fig. 4.)
  - (*b*) Sides more or less waved.
    - *Red Astrachan.* — Leaf waves "crinkly" or wrinkled, not reaching to midrib. (Fig. 5.)
    - *Oldenburg.* — Leaves broad at base and apex; shoots few and stout. (Fig. 6.)
    - *Wealthy.* — Leaf relatively narrow at base and apex; midrib often tending to spiral form or reflexed at tip. (Fig. 7.)

A. Varieties important in Massachusetts — *Concluded.*

2. Leaves more or less distinctly folded.

(*a*) Folding "saucer-shaped" or broad U-shaped.

Baldwin. — Leaves broad, distinctly saucer-shaped; serrations sharp, close set and usually curved. (Fig. 8.)

Roxbury Russet. — Serrations distinct and only moderately sharp; bark olive green. (Fig. 9.)

Winter Banana. — Leaves rather long and narrow; serrations regular and dull; branches long and slender, yellowish. (Fig. 10.)

(*b*) Folding narrow U-shaped.

(1) Serrations dull.

Williams. — Waves large, coarse; serrations uniform; growth open; bark yellowish. (Fig. 11.)

Wolf River. — Leaf only moderately folded, oval, narrowing at base and apex; serrations coarse, dull. (Fig. 12.)

Yellow Transparent. — Leaves broad at base and rather narrow at apex; serrations uniform, shallow. (Fig. 13.)

(2) Serrations at least moderately sharp.

Delicious. — Leaves narrow at apex; serrations coarse and distinct. (Fig. 14.)

Wagener. — Leaves strongly folded; midrib much reflexed; shoots stout with large buds. (Fig. 15.)

Northern Spy. — Leaves sometimes little folded, upright; serrations sharp; shoots upright; bark russet with many small dots. (Fig. 16.)

B. Varieties of minor importance in Massachusetts.

1. Leaves usually only slightly folded, serrations rarely sharp.

(*a*) Leaves small, coarsely and irregularly serrate.

Jonathan. — Leaves very small, narrow at base and apex, sometimes folded; tree slender, of open habit. (Fig. 17.)

King David. — Leaves narrow at base but wider at apex; tree strong and vigorous. (Fig. 18.)

Stayman. — Leaves nearly round, spur leaves and some shoot leaves sharply serrate; tree vigorous. (Fig. 19.)

(*b*) Leaves medium-sized, serrations rather fine and regular.

Opalescent. — Leaves sometimes slightly waved, rather narrow at apex; bark of shoots very smooth. (Fig. 20.)

2. Leaves distinctly folded and waved.

(*a*) Serrations distinct and rather sharp.

Fall Pippin. — Leaves long, sharply and distinctly serrate; tree vigorous. (Fig. 21.)

Hubbardston. — Serrations moderately sharp; midrib reflexed; bark olive green. (Fig. 22.)

Grimes. — Serrations sharp and distinct; midrib reflexed. (Fig. 23.)

Tompkins King. — Tree vigorous with long stout shoots, does not branch freely. (Fig. 24.)

(*b*) Serrations not sharp but rather dull.

Ben Davis. — Leaves rather narrow, grayish and woolly. (Fig. 25.)

Esopus Spitzenburg. — Serrations dull and regular; midrib usually only slightly reflexed. (Fig. 26.)

Tolman. — Leaves narrow at base and strongly waved; serrations only moderately dull. (Fig. 27.)

The varieties in the foregoing classification are illustrated in the following pages. These cuts are approximately two-thirds life size. While, as stated in the text, the size of the leaves may vary with cultural conditions, yet these may be taken as fairly representative, and are comparable one with another.

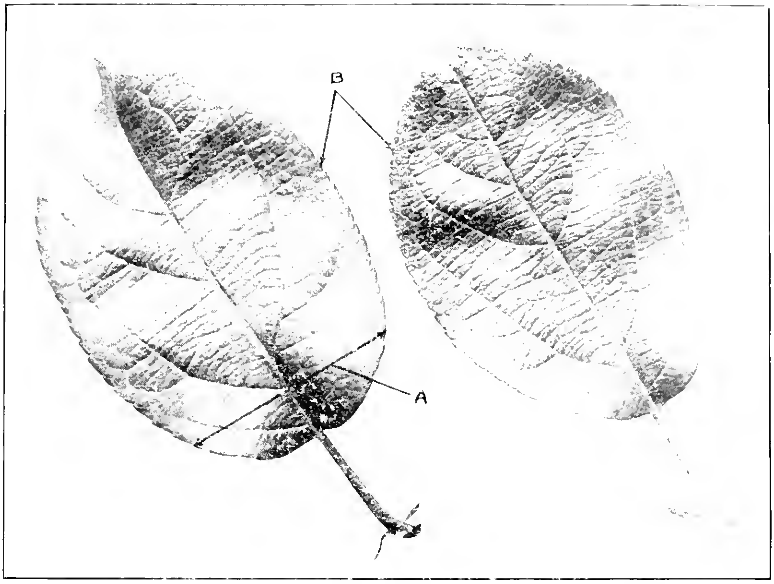


Photo by R. L. Coffin

FIG. 2. — GRAVENSTEIN. Blade large, flat, rounded or rather narrow at base (A); serrations moderately sharp and shallow (B), fairly regular.

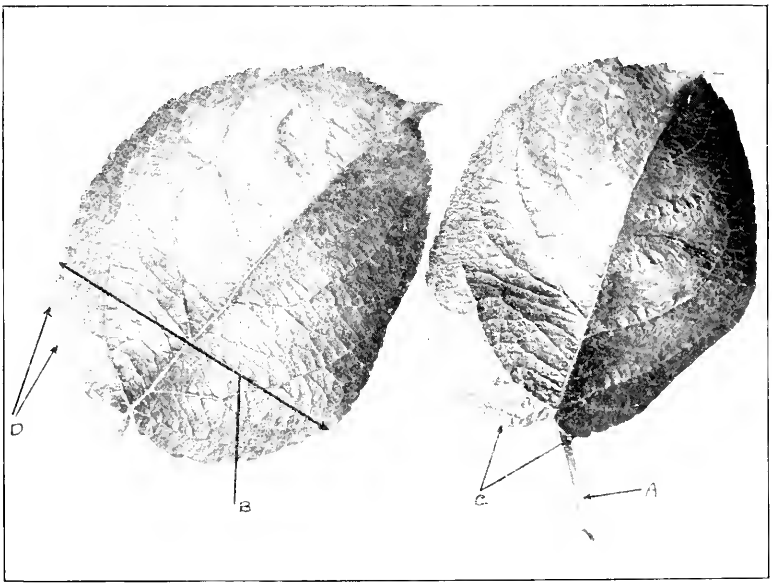


FIG. 3. — MCINTOSH. Petiole short (A); blade large, flat or slightly folded near edge, broad (B) and heart shaped (C) at base, deep bluish green; serrations rather dull and shallow, especially at base (D).

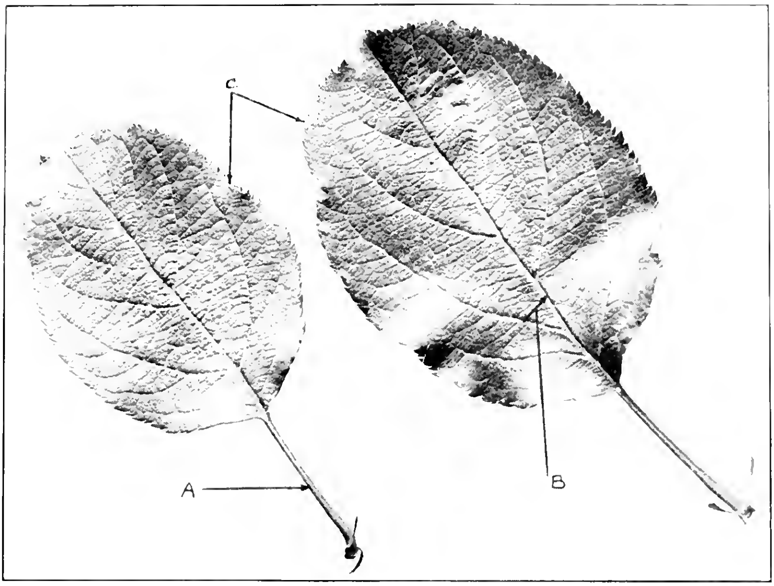


Photo by R. L. Coffin.

FIG. 4. — RHODE ISLAND GREENING. Petiole long (A); blade large, flat, deep clear green; vein angle sharp (B); serrations very sharp, deep and distinct (C).

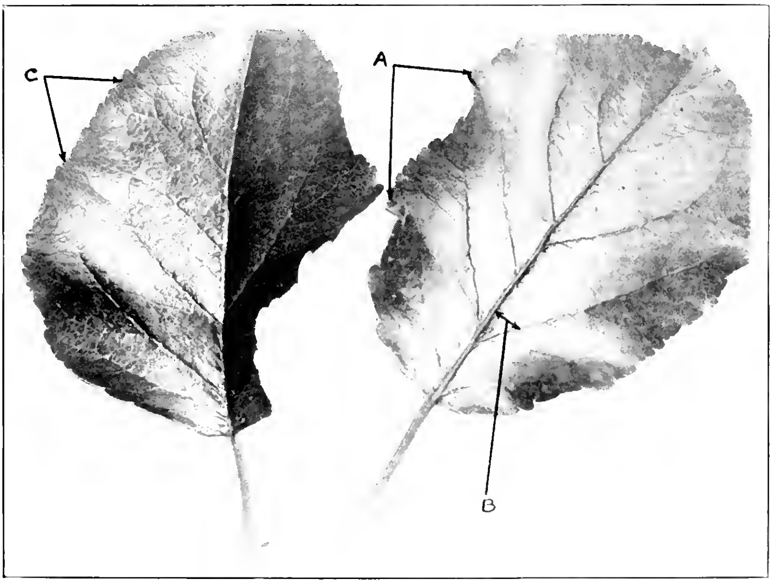


FIG. 5. — RED ASTRACHAN. Blade large, broad, flat, with waved and wrinkled edges (A); vein angle sharp (B); serrations dull and irregular (C).

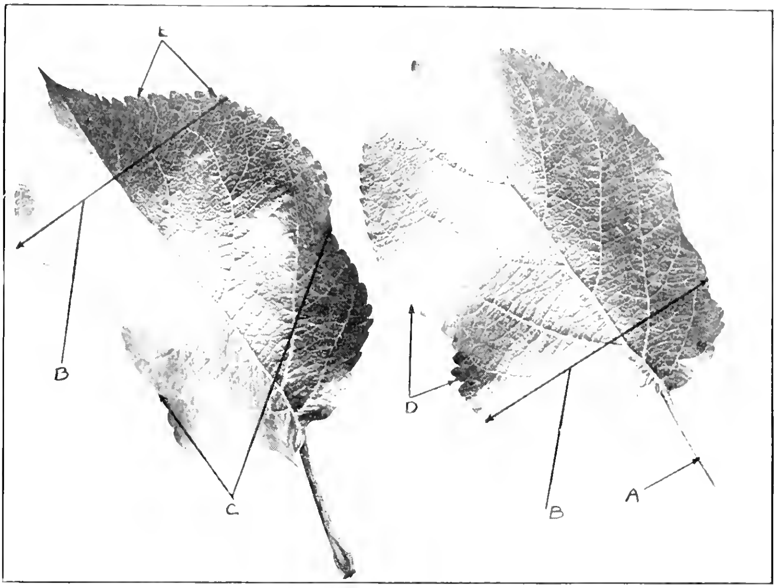


Photo by R. L. Coffin.

FIG. 6.—OLDENBURG. Petiole long (A), blade above medium to large, broad at base and apex (B), somewhat folded (C), and waved (D); serrations moderately sharp and irregular (E).

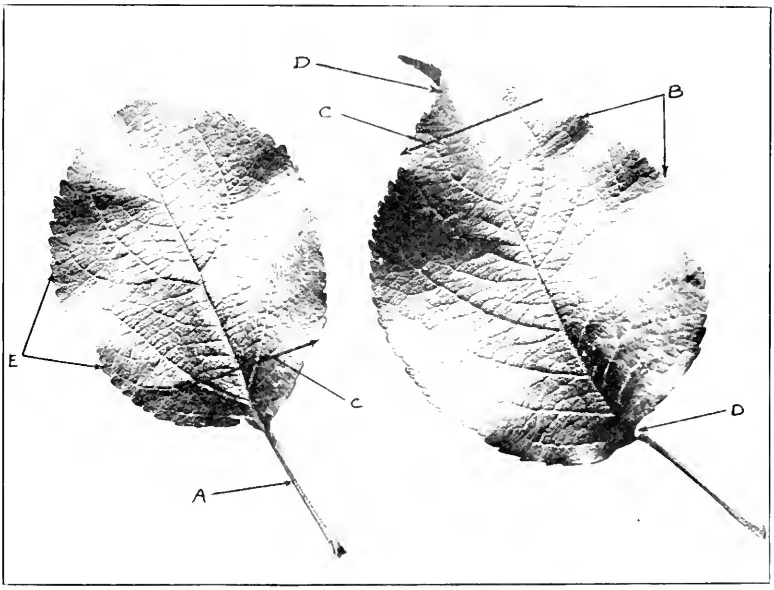


Photo by R. L. Coffin.

FIG. 7.—WEALTHY. Petiole long (A); blade moderately large, flat, with waved edges (B), narrow at base and apex (C); midrib reflexed or spiral (D); serrations rather dull (E).

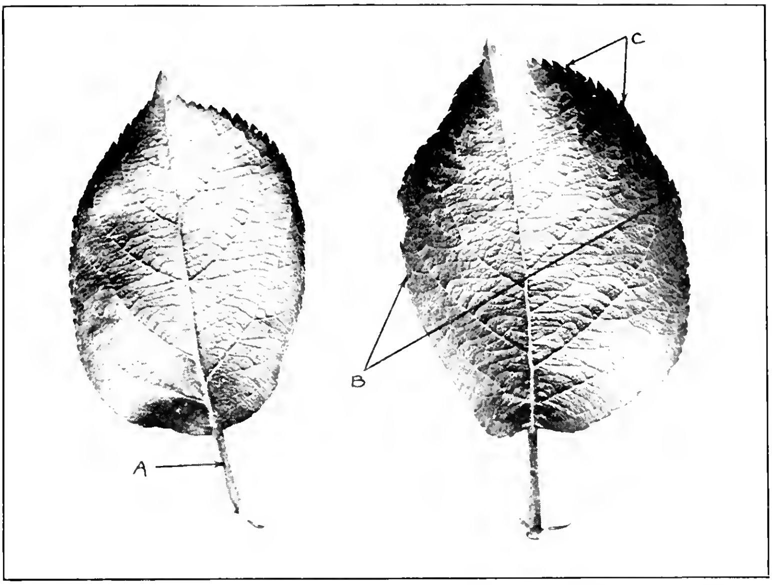


Photo by R. L. Coffin.

FIG. 8. — BALDWIN. Petiole short (A); blade large, broad, with "saucer shaped" folding (B); serrations sharp, close set, usually curved (C).

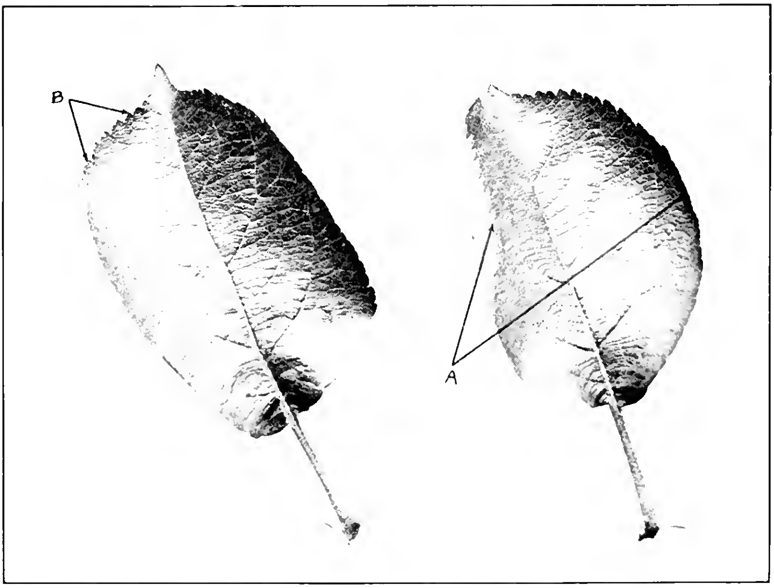


Photo by R. L. Coffin.

FIG. 9. — ROXBURY RUSSET. Blade large, broad, with "saucer shaped" folding (A); serrations not sharp nor curved (B).

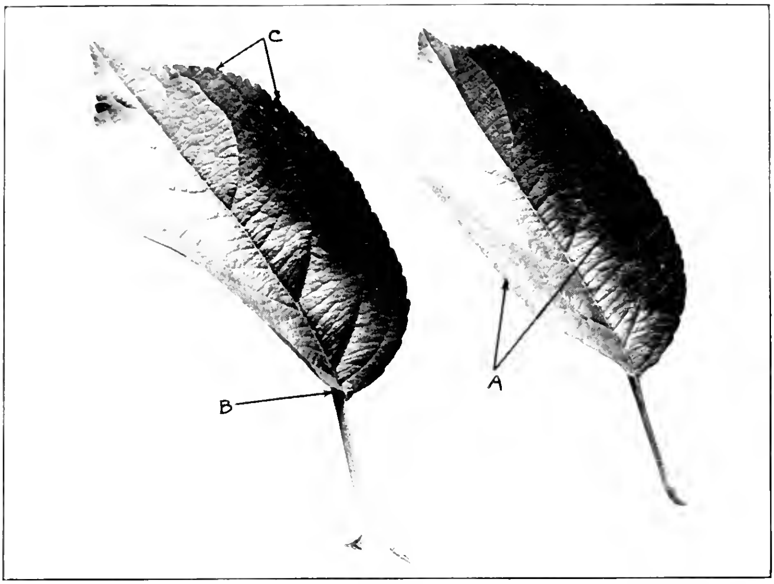


Photo by R. L. Coffin.

FIG. 10. — WINTER BANANA. Blade medium size, rather long and narrow, folded (A); midrib bent at base (B); serrations rather dull and shallow (C).

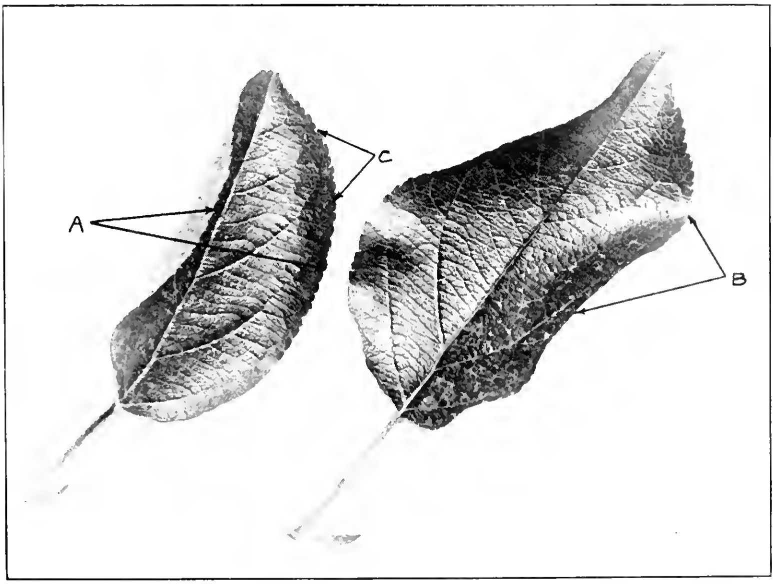


FIG. 11. — WILLIAMS. Blade medium size, folded (A) and often coarsely waved (B); serrations rather dull and quite regular (C).

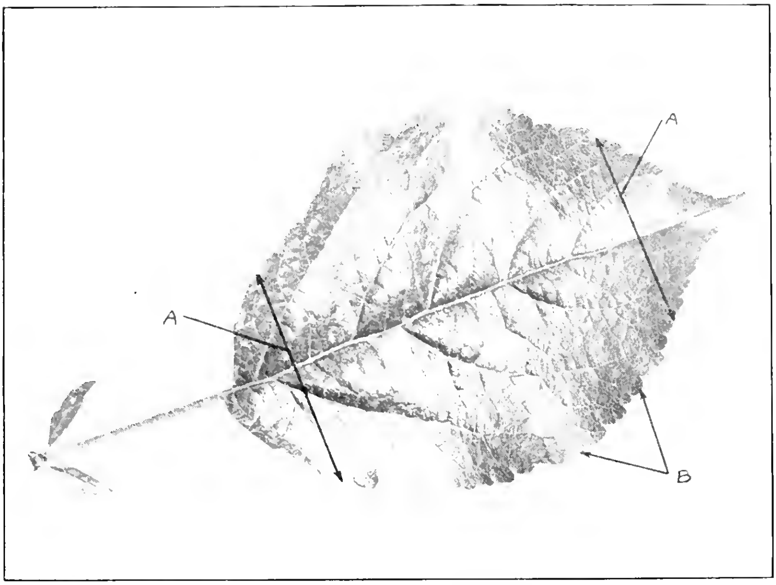


Fig. 12. — Wolf River. Petiole long; blade often only slightly folded, narrow at base and apex (A); serrations coarse and dull, often double (B).

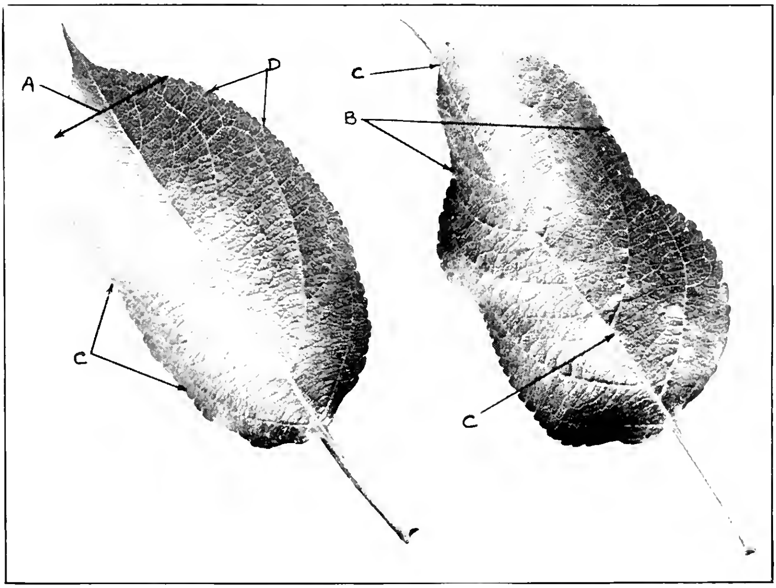


Photo by R. L. Coffin.

Fig. 13. — Yellow Transparent. Blade medium size, rather broad at base and narrow at apex (A), more or less folded (B), more or less waved, and often spiral (C); serrations rather dull, shallow and quite regular (D).

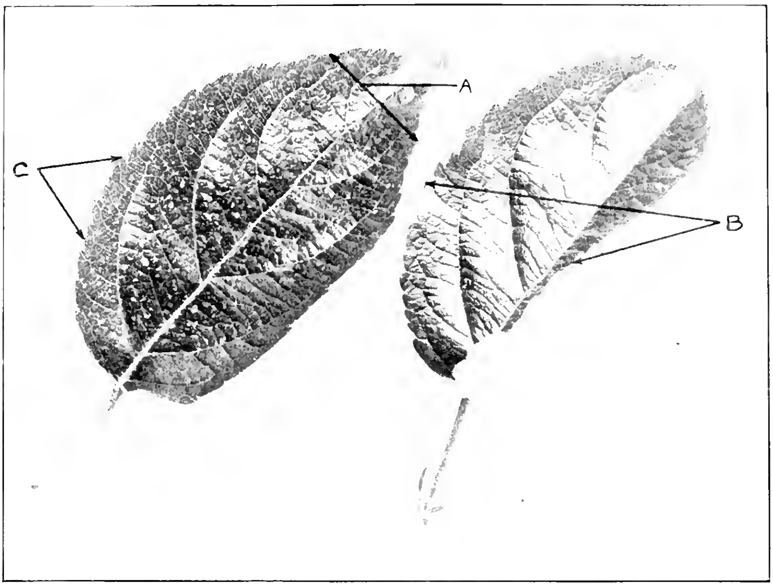


Fig. 14. —Delicious. Blade medium size, apex narrowing to point (A), partly folded (B); serrations moderately sharp, coarse and rather irregular (C).

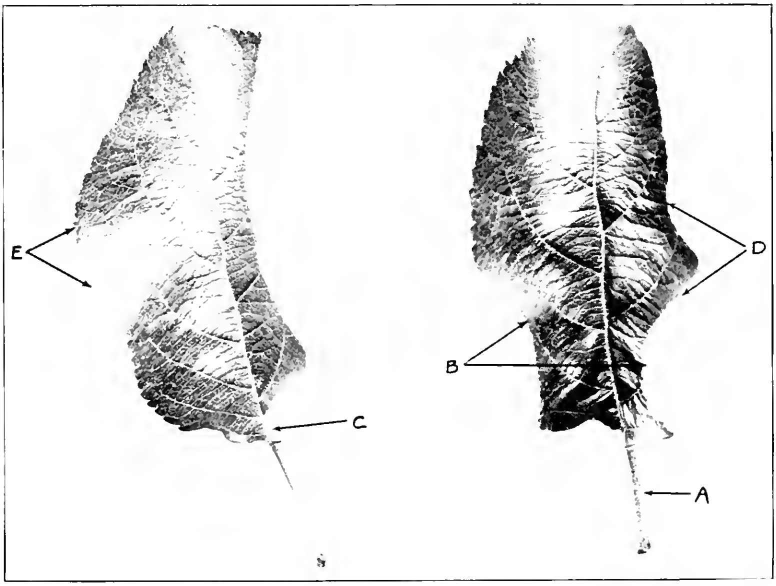


Photo by R. L. Cof[illegible]n.

Fig. 15.—Wagener. Petiole short and stout (A); blade large, long and rather narrow, strongly folded (B), reflexed (C), and waved (D); serrations rather sharp, coarse and distinct (E).

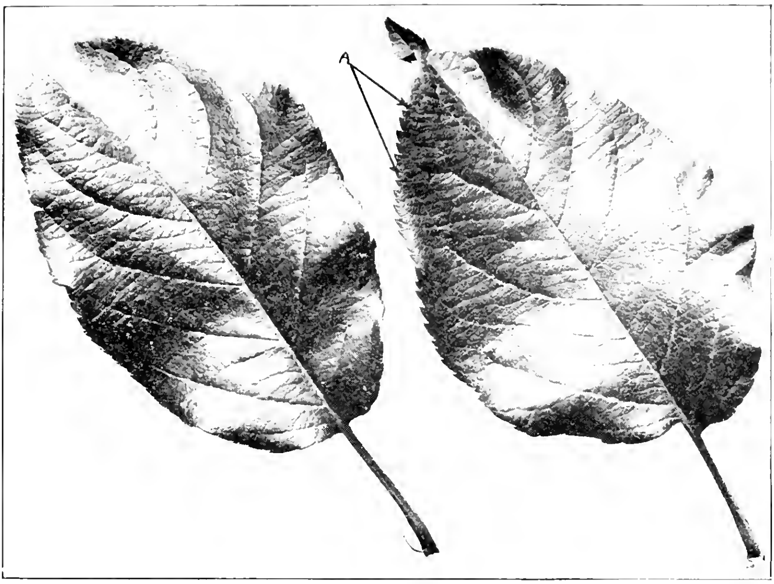


Photo by R. L. Coffin.

Fig. 16. — Northern Spy. Blade large, somewhat folded and waved, upright, often somewhat reflexed; serrations sharp, often curved (A).

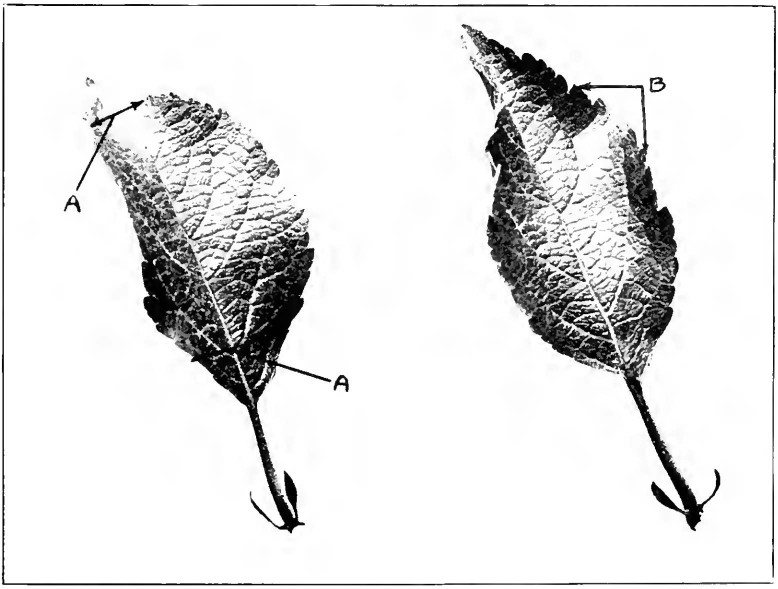


Photo by R. L. Coffin.

Fig. 17. — Jonathan. Blade very small, more or less folded, sometimes reflexed, narrow at base and apex (A); serrations moderately sharp, coarse and irregular (B).

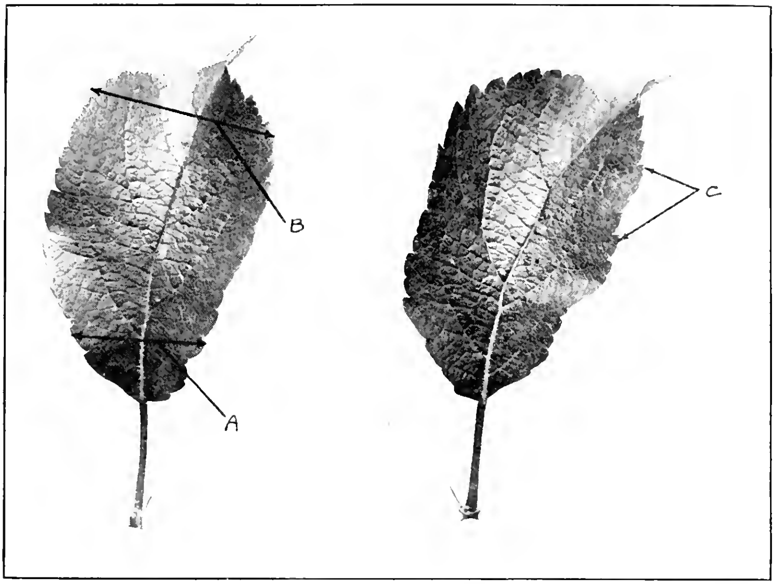


Photo by R. L. Coffin.

Fig. 18. — King David. Blade small, narrow at base (A), but broader at apex (B), more or less folded and reflexed; serrations moderately sharp, coarse and irregular (C).

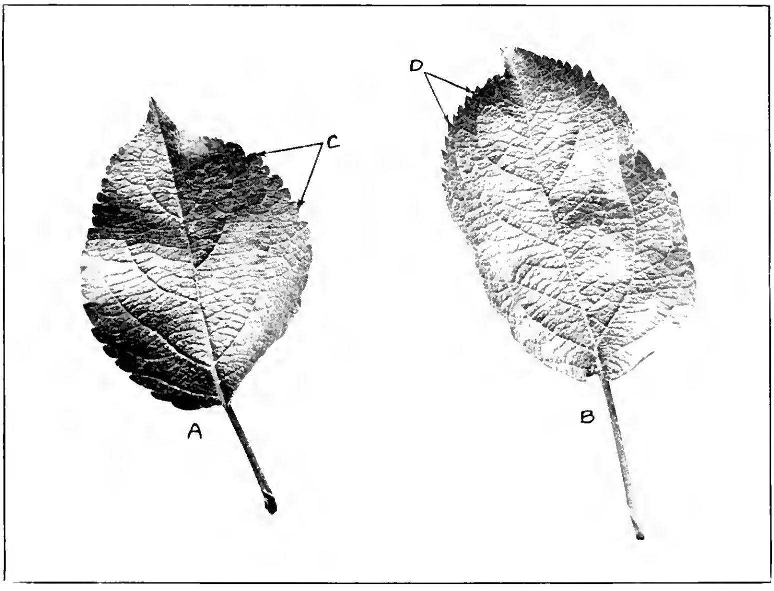


Photo by R. L. Coffin.

Fig. 19. — Stayman. Blade medium or below in size, usually nearly round (A), sometimes oblong (B); serrations usually dull and coarse (C), sometimes sharp (D). An exceptional variety, often having leaves of two distinct types.

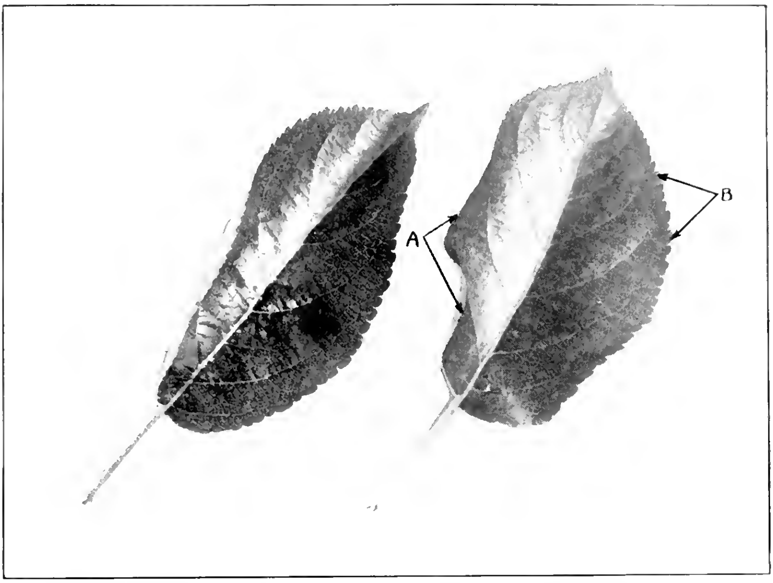


FIG. 20. — OPALESCENT. Blade medium size, somewhat folded, sometimes slightly waved (A); serrations rather dull, fine and regular (B).

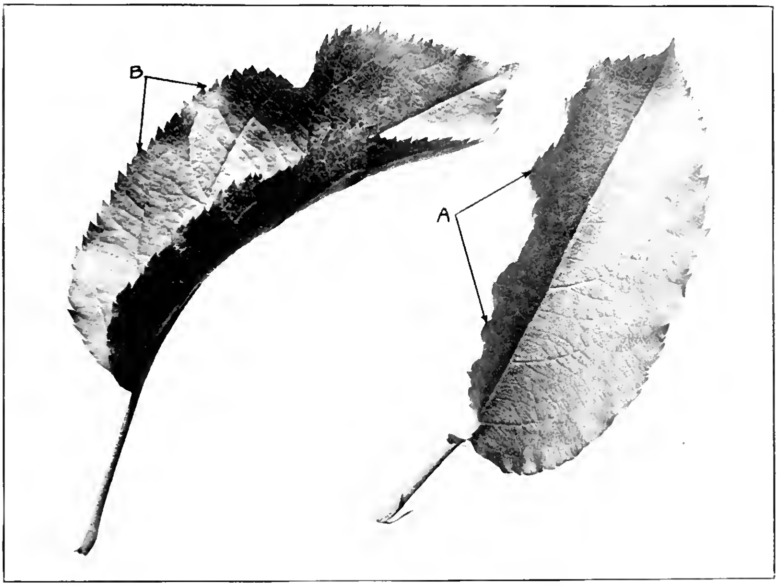


Photo by R. L. Coffin.

FIG. 21. — FALL PIPPIN. Blade large, long and rather narrow, folded, reflexed and waved or wrinkled (A); serrations sharp, coarse and distinct (B).

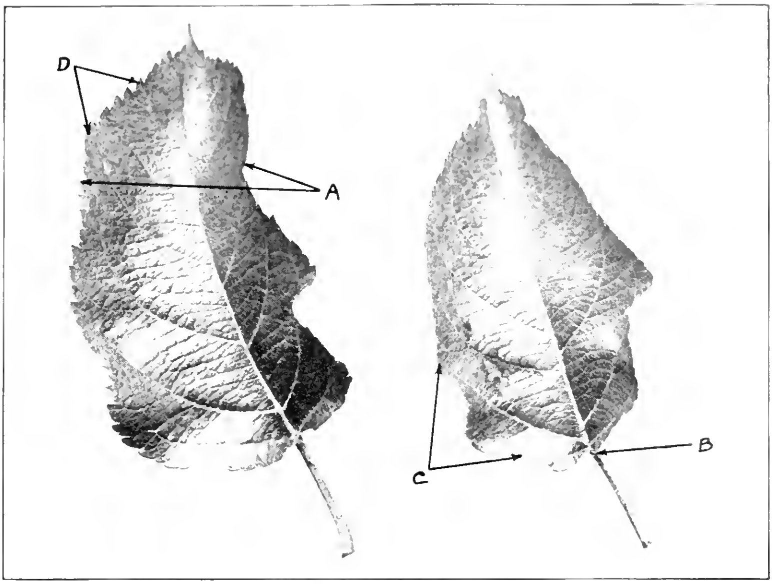


Photo by R. L. Coflin.

FIG. 22. — HUBBARDSTON. Blade medium size, folded (A), reflexed (B), and waved (C); serrations rather sharp and distinct, rather irregular (D).

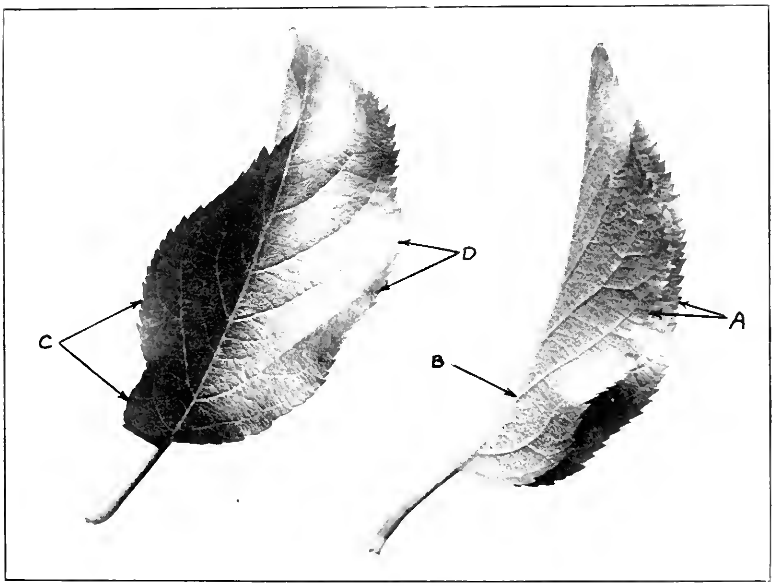


Photo by R. L. Coflin.

FIG. 23. — GRIMES. Blade medium size, folded (A), reflexed (B), and waved (C); serrations sharp, regular and distinct (D).

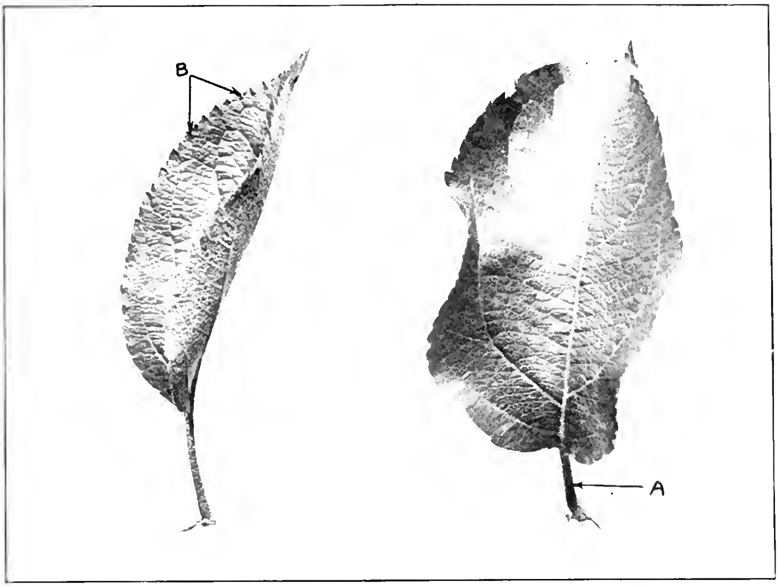


Photo by R. L. Coffin.

FIG. 24. — TOMPKINS KING. Petiole short (A); blade large, folded and reflexed, usually waved; serrations sharp, distinct and quite regular (B).

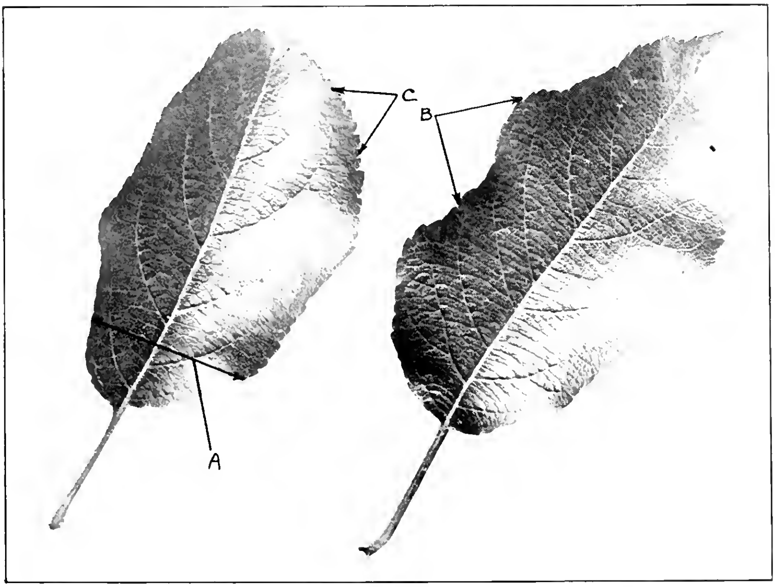


Photo by R. L. Coffin.

FIG. 25. — BEN DAVIS. Blade medium size or above, long and narrow especially at base (A), folded, reflexed and waved (B); serrations dull, rather fine and irregular (C).

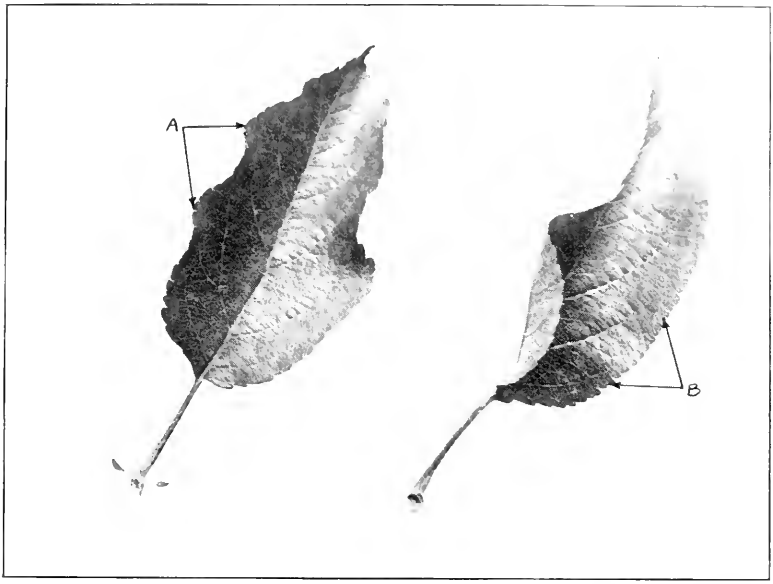


Photo by R. L. Coffin.

FIG. 26. — ESOPUS SPITZENBURG. Blade medium size, folded, reflexed and more or less waved (A); serrations rather dull and quite regular (B).

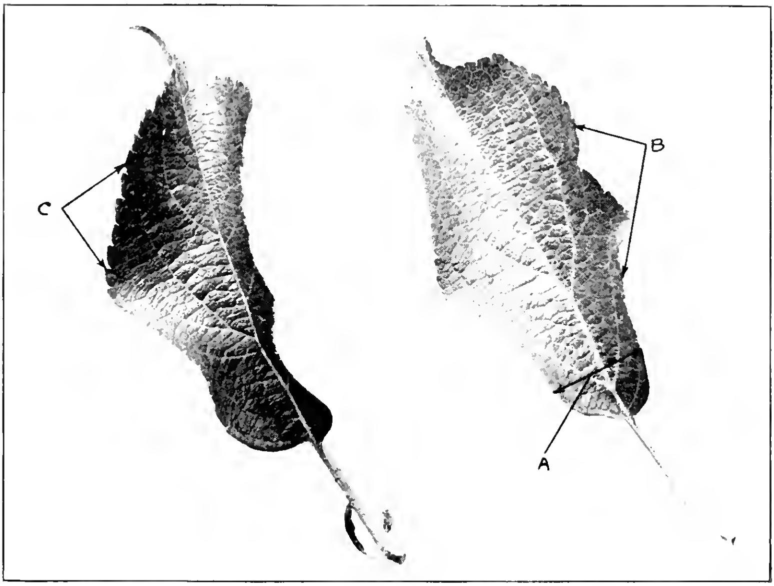


Photo by R. L. Coffin.

FIG. 27. — TOLMAN. Blade medium size, very narrow at base (A), narrow at apex, folded, reflexed and waved (B); serrations rather dull and coarse (C).

Description of Varieties.

There are many leaf characters that are of considerable value in identifying varieties that cannot be well shown in photographs. They have been discussed in the text. In order to present these characters the following technical descriptions of the leaf characters of the varieties illustrated are presented: —

Baldwin. — Petiole medium. Blade above medium size, folded near margin, straight or slightly reflexed, not waved, broad oval, broad at base and very broad at apex, nearly erect, rather thin, smooth, fine texture with little pubescence. Serrations sharp, strongly forward, medium size, fairly regular, usually curved, rather deep and close set. Color medium green. (Fig. 8.)

Ben Davis. — Petiole long, medium size. Blade below medium size, folded, often reflexed, waved, narrow oval, very narrow at base, nearly spreading, rather thin, smooth with considerable pubescence. Serratures dull, moderately forward, rather small and shallow, sometimes slightly curved, quite regular. Color slightly grayish green. (Fig. 25.)

Delicious. — Petiole length, short to medium. Blade below medium size, slightly folded, straight or slightly reflexed, even, ovate, apex narrowing into the point, rather erect, thick, rather coarse texture with little pubescence. Serratures moderately sharp, rather coarse and deep, irregular. Color deep green. (Fig. 14.)

Esopus Spitzenburg. — Petiole medium. Blade below medium in size, more or less folded and waved, slightly reflexed, oval or ovate usually narrowing at apex, medium in texture and pubescence. Serratures rather dull, small and rather shallow, fairly regular. Color medium green. (Fig. 26.)

Fall Pippin. — Petiole medium long, stout. Blade large, folded, reflexed and waved, ovate with apex merging into acute or acuminate point, rather smooth and shining. Serratures sharp, deep and distinct, not curved, rather irregular. Color bright clear green. (Fig. 21.)

Gravenstein. — Petiole medium. Blade large, flat, not waved, oval, smooth and shining. Serratures rather sharp, shallow, fairly regular. Color medium green. (Fig. 2.)

Grimes. — Petiole medium. Blade medium size, strongly folded, waved and reflexed, long and narrow, narrowing at base and apex, rather thin, smooth and shining, with little pubescence. Serrations sharp, distinct and rather deep, rather irregular. Color medium green. Grimes resembles Wagener, but it has less pubescence, is thinner, and has finer and sharper serrations. (Fig. 23.)

Hubbardston. — Petiole rather short, medium size. Blade below medium, folded, more or less waved, reflexed, generally ovate, rounded at base and generally narrow at apex, nearly erect, medium thickness, dull, rather coarse texture with considerable pubescence. Serratures fairly sharp, medium size, moderately deep and distinct, fairly regular. Color deep grayish green. (Fig. 22.)

Jonathan. — Petiole short and rather slender. Blade very small, more or less folded, waved, sometimes reflexed, oval, narrow at base and apex, rather spreading, rather coarse texture with considerable pubescence. Serratures rather dull, rather coarse, shallow and irregular. Color grayish green. (Fig. 17.)

King David. — This is like Jonathan, except that the leaf is somewhat larger, distinctly broader in the apex, less apt to be folded and with somewhat less pubescence. (Fig. 18.)

McIntosh. — Petiole short and rather stout. Blade large, flat or slightly folded near margin, straight, not waved, broad oval, often cordate at base, spreading, rather coarse and thick, with considerable pubescence. Serratures dull, medium size, very shallow at base, fairly regular. Color deep grayish blue green. (Fig. 3.)

Northern Spy. — Petiole generally rather long and slender. Blade medium size,

more or less folded and waved, often slightly reflexed, ovate, erect, rather thin. smooth with little fine pubescence. Serratures rather sharp, medium size, rather shallow, fairly regular. Color clear medium green. (Fig. 16.)

Oldenburg. — Petiole long. Blade above medium to large, more or less folded, slightly reflexed, distinctly waved, broad oval, broad at base and apex, spreading, medium thickness. rather dull surface with medium pubescence. Serratures rather dull, medium in size and depth, irregular. Color medium green. (Fig. 6.)

Opalescent. — Petiole medium. Blade medium size, somewhat folded, sometimes waved, oval, rather narrow at base, apex narrowing into the point, spreading, medium thickness, smooth and shining with little pubescence. Serratures dull, rather small, of medium depth, quite regular. Color medium green. (Fig. 20.)

Red Astrachan. — Petiole medium. Blade large, flat or slightly folded, waved or wrinkled, broad oval, broad at apex, spreading, medium thickness, dull surface with a little pubescence. Serratures dull, medium in size and depth, rather irregular. Color dull medium green. (Fig. 5.)

Rhode Island Greening. — Petiole long, medium size. Blade large, flat or reverse curved, not waved, broad oval, rounded or narrow at base, broad at apex, spreading or drooping, smooth with little pubescence. Serratures very sharp and distinct, rather deep, fairly regular. Color deep clear green. (Fig. 4.)

Roxbury Russet. — Petiole medium or short, rather stout. Blade medium in size, folded near edge, not waved nor reflexed, broad oval, broad at base and apex, spreading, rather smooth with medium pubescence. Serratures only moderately sharp, rather small, not deep, rather irregular. Color deep green. Much like Baldwin, but the serratures are not so sharp nor so close set and are not curved. (Fig. 9.)

Stayman. — Petiole short to medium. Blade rather small, roundish or broad oval, partly folded, not waved nor reflexed, spreading, rather thick, coarse texture with medium pubescence. Serratures dull and coarse to sharp and small. Color deep green. Stayman seems to be unique in having distinct types of leaves as shown in Fig. 19.

Tolman. — Petiole medium. Blade medium, folded, reflexed and waved, narrow oval, narrow at base and apex, spreading, medium texture with considerable pubescence. Serratures moderately sharp, medium size, quite distinct, generally quite regular. Color deep bluish or grayish green. (Fig. 27.)

Tompkins King. — Petiole rather short and stout. Blade medium to large, folded, more or less waved and reflexed, rather long oval, rather narrow at base and apex, spreading, medium thickness with little pubescence. Serratures sharp, medium to small, shallow and close set. Color medium green. (Fig. 24.)

Wagener. — Petiole, medium or short, stout. Blade medium or above, strongly folded and reflexed, more or less waved, oval with medium base and apex, erect, rather thin with moderate pubescence. Serratures quite sharp, rather coarse, deep and distinct, not curved. Color medium green or slightly grayish. Wagener resembles Grimes, but the leaf is coarser, the serrations not quite so sharp, and it has more pubescence. (Fig. 15.)

Wealthy. — Petiole medium or rather long, slender. Blade medium or above, nearly flat, often somewhat reflexed, often spiral and waved, oval with narrow base and apex, spreading, thick and with little pubescence. Serrations dull, medium in size and depth, somewhat irregular. Color medium green. Wealthy resembles Oldenburg, but the serrations are duller, the blade less folded and much narrower at the base and apex. (Fig. 7.)

Williams. — Petiole medium, rather slender. Blade medium size, partly folded, somewhat reflexed, sometimes coarsely waved, spreading, rather coarse with little pubescence. Serratures dull, small and shallow, regular. Color medium green. (Fig. 11.)

Winter Banana. — Petiole short and stout. Blade medium size, folded near margin, midrib bent at base, not often waved, narrow oval, spreading, medium

thickness with little pubescence. Serrations rather dull and shallow, pointing well forward. Color rather pale green. (Fig. 10.)

Wolf River. — Petiole medium. Blade flat or somewhat folded, often waved and wrinkled, often reflexed, oval, narrow at base and apex, spreading, medium thickness, rather coarse with medium pubescence. Serratures very dull, quite distinct and rather irregular, often double. Color medium green. (Fig. 12.)

Yellow Transparent. — Petiole medium. Blade medium size, more or less folded, often waved and somewhat reflexed, often spiral especially near tips of shoots, rather narrow oval, rather narrow at apex, smooth, rather fine texture with considerable pubescence. Serratures dull, rather small and shallow, quite regular. Color rather pale green. (Fig. 13.)

Glossary.

In the foregoing descriptions there are a number of words that are used in a restricted, technical sense. Definitions of the technical meaning of these words are here given: —

Acute: sharp pointed.
Acuminate: very sharp pointed.
Apex: about one-third of the leaf blade. (See Fig. 1.)
Base: same as apex, but referring to the opposite end.
Blade: the leaf, barring petiole and stipules. (See Fig. 1.)
Cordate: heart-shaped; applied to shape of leaf base. (See McIntosh, Fig. 3.)
Close set: referring to serratures having little space between. (See Baldwin, Fig. 8.)
Curved: applied to "teeth" of serratures. (See Baldwin, Fig. 8.)
Distinct: having spaces between the "teeth" of serratures, the opposite of close set. (See Fall Pippin, Fig. 21.)
Drooping: applied to the angle of leaf and the shoot from which it grows; a very wide angle.
Erect: the opposite of drooping; a sharp angle between leaf and shoot.
Folded: the halves of the leaf curved upward toward each other.
Irregular: serratures of varying sizes.
Midrib: the main vein along the middle of the blade.
Point: the extreme tip of the leaf blade.
Pubescence: the short hairy growth found mainly on the under side of the leaf blade.
Reflexed: having the blade curved backward or downward.
Regular: serratures all of equal size.
Reverse curved: the midrib and blade bent slightly like the letter S.
Serratures, serrations: the notches on the margin of the leaf blade.
Spreading: the usual angle of the leaf and shoot; between erect and drooping.
Spiral: a slight twisting of the leaf blade. (See Wealthy, Fig. 17.)
Texture: applied to the surface of the leaf blade, due mainly to character of the net veins.
Waved: having undulating leaf margins.
Wrinkled: the same as waved, but with smaller undulations.

BULLETIN No. 209.

DEPARTMENT OF POMOLOGY.

EXPERIMENTS IN SOIL MANAGEMENT AND FERTILIZATION OF ORCHARDS.

BY J. K. SHAW.

The Old Station Orchard.[1]

The orchard experiment here reported was begun in 1890 and has continued to the present time. It is, so far as the writer's knowledge goes, the oldest orchard fertilizer experiment in America, and perhaps in the world. The arrangement of the orchard is shown on page 34. It lies on a gentle western slope and is bordered on the west and north by grassland. To the east and south the slope is steeper and covered by a heavy growth of forest trees. The orchard and forest are separated by an open space which in the writer's judgment is sufficient to prevent any injurious influence on the orchard trees from root trespass, though there may possibly have been an injurious effect from shading. This, however, is distributed quite evenly over the whole orchard.

The soil is a strong and retentive gravelly loam underlain by a fairly compact subsoil. It is well supplied with moisture. A ditch above the orchard prevents surface wash from the forest slope above. It was originally somewhat overmoist, especially on plot 3, which is slightly lower than plots 4 and 5. This may have influenced in some degree the growth and yield of this plot, but in the writer's judgment any such influence is small even if it exists at all. Before the trees were planted tile drains were laid to care for surplus water.

[1] This experiment was planned and started by the late Dr. C. A. Goessmann as director and chemist of the State Experiment Station. For most of its life it has been under the direction of Dr. Wm. P. Brooks. The details of management and recording of data have been in the hands of several different men, recently of E. F. Gaskill and R. L. Coffin. The writer is responsible for the tabulation and interpretation of the data.

Below is shown the arrangement of the plots and trees. The trees are spaced 40 × 30 feet, with an additional space of 14 feet between plots. Plot 1 is at the north end of the orchard.

PLOT 1. — MANURE, 10 TONS.

Rhode Island Greening.	Rhode Island Greening.	Rhode Island Greening.
Roxbury Russet.	Roxbury Russet.	Roxbury Russet.
Baldwin.	Baldwin.	Baldwin.
Gravenstein (died before 1907).	Gravenstein.	Gravenstein (died in 1919).

PLOT 2. — ASHES, 2,000 POUNDS.

Rhode Island Greening.	Rhode Island Greening.	Rhode Island Greening.
Roxbury Russet.	Roxbury Russet.	Roxbury Russet (died in 1919).
Baldwin.	Baldwin.	Baldwin.
Gravenstein.	Gravenstein.	Gravenstein.

PLOT 3. — NO FERTILIZER.

Rhode Island Greening.	Rhode Island Greening.	Rhode Island Greening.
Roxbury Russet.	Roxbury Russet.	Roxbury Russet.
Baldwin (died about 1913).	Baldwin.	Baldwin.
Gravenstein.	Gravenstein.	Gravenstein.

PLOT 4. — BONE, 600 POUNDS; MURIATE OF POTASH, 200 POUNDS.

Rhode Island Greening.	Rhode Island Greening.	Rhode Island Greening.
Roxbury Russet (died in 1907–08).	Roxbury Russet.	Roxbury Russet.
Baldwin.	Baldwin.	Baldwin.
Gravenstein.	Gravenstein.	Gravenstein.

PLOT 5. — BONE, 600 POUNDS; LOW-GRADE SULFATE OF POTASH, 400 POUNDS.

Rhode Island Greening.	Rhode Island Greening.	Rhode Island Greening.
Roxbury Russet.	Roxbury Russet.	Roxbury Russet.
Baldwin.	Baldwin.	Baldwin.
Gravenstein.	Gravenstein.	Gravenstein.

Fertilizer Treatment.

Previous to 1889 the soil was in rather poor condition, but had been gradually improved by cultivation in corn and other cereals and grass. The manurial treatment was begun in the spring of 1889, and the following annual applications were continued up to and including 1916. Since 1916 no manure or fertilizer has been applied.

Plot.	Fertilizer.	Pounds per Acre.
1	Barnyard manure	20,000
2	Ashes	2,000
3	Check, no fertilizer	
4	Ground bone	600
	Muriate of potash	200
5	Ground bone	600
	Low-grade sulfate of potash	400

The fertilizer and manure have been applied on various dates, generally between April 1 and May 15, though in 1906 they were not applied until July 2.

Soil Management.

During the period from 1889 to 1893 various crops, such as barley, oats, corn, vetch and soy beans, were grown in the orchard. In the fall of 1893 it was seeded to rye and grass, and the sod then established continued until the fall of 1910. For the first few years small circles around the trees were kept free from grass by hand culture. Until 1902 the grass was cut usually twice each year, made into hay and removed from the orchard. In that year the first crop was made into hay and the second allowed to lie in the orchard. Since 1902 no hay has been removed, but the grass has been cut and allowed to lie where it fell. In November, 1910, four strips, each about 8 to 12 feet wide, were plowed the long way of the orchard. These strips have since been kept in cultivation by harrowing four to eight times during the summer; and usually about August 25 a cover crop of oats or rye has been sown. The grass along the tree rows has been cut and allowed to lie as before.

The history of the soil management, therefore, falls into four periods: —

1. With various intercrops . . . . 1889–1893, 5 years.
2. In sod with grass removed . . . . 1894–1902, 9 years.
3. In sod mulch . . . . 1903–1910, 8 years.
4. In strip cultivation . . . . 1911–1920, 10 years.

The fourth period might be subdivided between 1916 and 1917, marking the cessation of the application of fertilizer and manure.

Orchard Management.

The trees have been pruned in most years, at least since they have been in bearing. Heading back the new growth has been practiced more or less, and all dead wood has been removed.

During the early years apparently no spray treatment was given. Beginning in 1902 annual treatments for San José scale have been given which have kept the pest from doing serious damage to the trees. Gen-

erally lime-sulfur has been used for scale control, but in 1912 and 1913 miscible oil was applied in the late fall. This was followed by the dying of branches on some trees, which was attributed in part to the use of the oil, so that it was discontinued. One or two summer sprays have been given except in a very few years when the crop promised to be very light. Curculio injury has been common in most years, and in 1913 the red bug was found to be present. Partial control of these pests has been secured by the use of nicotine preparations in the spray. During the early years copper sulfate preparations and Paris green, and recently lime-sulfur and arsenate of lead, have been used in the summer sprays.

No records of growth were taken previous to 1902. Beginning in that year the circumference of the trunk 6 inches from the ground has been measured annually except in the years 1905, 1906, 1910, 1912 and 1918. Records of the yields of drops and picked fruit for each variety from each plot have been taken each year. The yield of individual trees has not been taken.

Five trees have died since the orchard came into bearing. One Gravenstein in plot 1 died before 1907, and another in 1919. The remaining Gravenstein in this plot was girdled by mice in 1907–08, but was bridge grafted and is now in good condition. One Baldwin in plot 3 died about 1913, one Roxbury Russet in plot 4 died in 1907–08, and one in plot 2 in 1919. (See page 34.) These have all been replaced, but none of the young trees is in bearing. In the tables given for trunk circumference the missing trees are omitted from the averages, but no corrections are made in yields.

Growth Records.

The only record of tree growth is that of trunk circumference which has been taken in most years beginning in 1902. Fig. 1 shows the averages of these measurements by plots. It may fairly be assumed that at the start the trees on the several plots averaged the same size. The differences in 1902 show what happened under the system of sod with removal of the hay. The manure and sulfate plots were alike, averaging about 27 inches. The graph shows that these two plots have steadily diverged up to the present time.

Certain years, such as 1904 and 1908, seem to have been especially favorable to tree growth, while 1917 was unfavorable. The writer has tried to correlate these variations in growth with rainfall, temperature, sunshine and size of crop, but without very much success. It is evident that no one of these factors is entirely responsible.

The relative growth on the different plots is more clearly shown in Fig. 2, where the average trunk circumference of the trees on plot 1 is shown as 100, and that of the other plots as percentages of plot 1. The steady decline of plot 5 from 100 to 89 per cent is clearly shown. Plot 2 (wood ashes) had fallen to about 88 per cent in 1902, and continued to fall off slowly until about 1912, but since that time it has nearly held its own. Plot 4 (bone and muriate) has behaved about the same as plot 2.

The check plot (plot 3) had fallen below 80 per cent at the commencement of our records, and continued to fall off rapidly up to 1911. From 1911 to 1915 it not only kept up with plot 1, but actually gained quite rapidly. Since 1915 it has kept even with plot 1 until the season of 1920, when plot 1 made remarkably strong growth, causing a relative falling off of plot 3 and of the other three plots as well.

The relative gain of plot 3 is beyond doubt due to cultivation of strips between the tree rows begun in the fall of 1910. As shown in Fig. 1, cultivation does not seem to have increased the growth on plot 1, but its effect is seen in all the other plots, though most strikingly in plot 3.

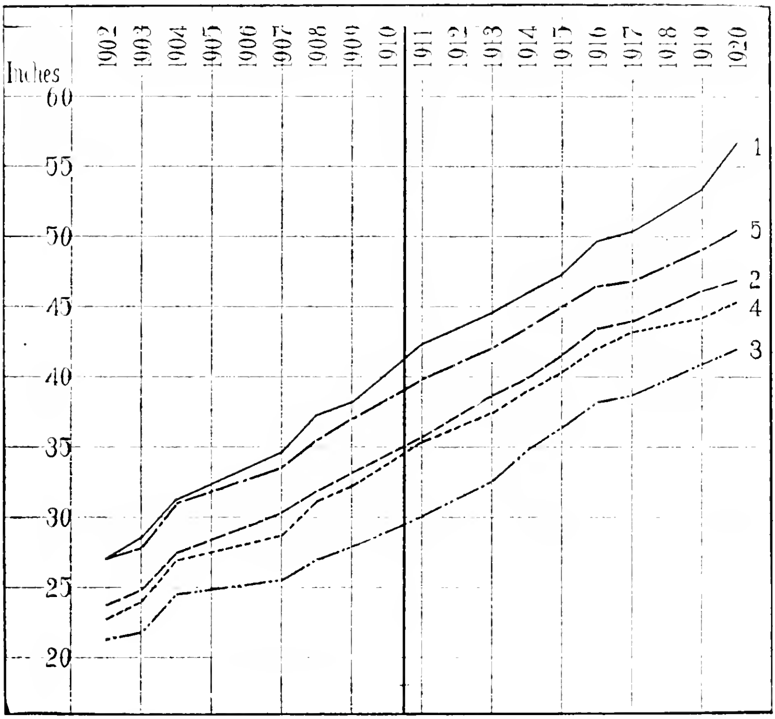


FIG. 1. — Increase in trunk circumferences. The perpendicular line marks the transition from sod mulch to strip cultivation. Plot numbers are shown at the right. See page 35 for treatments given.

No fertilizers of any kind have been applied since 1916, yet the growth on plot 1 has been well maintained as shown in Fig. 1. The other plots show a decrease in rate of growth since 1915, as shown in Fig. 2. It seems doubtful if this can be ascribed wholly to the cessation of fertilizer applications, because the decrease appears first in 1916, when fertilizers were applied, and it is seen in plot 3 which has never had any fertilizer applications. It seems more reasonable to suppose that the relative gain

on plots 2, 3, 4 and 5 since 1911 was due mostly to the stimulus of cultivation which lasted through 1915. From 1915 to 1919 the check plot maintained just about the same growth as plot 1, while plots 2, 4 and 5 fell away. This may indicate an effect of the withdrawal of the fertilizer applications, though, as stated above, the fact that it is seen in 1916 indicates that it is not wholly due to that cause.

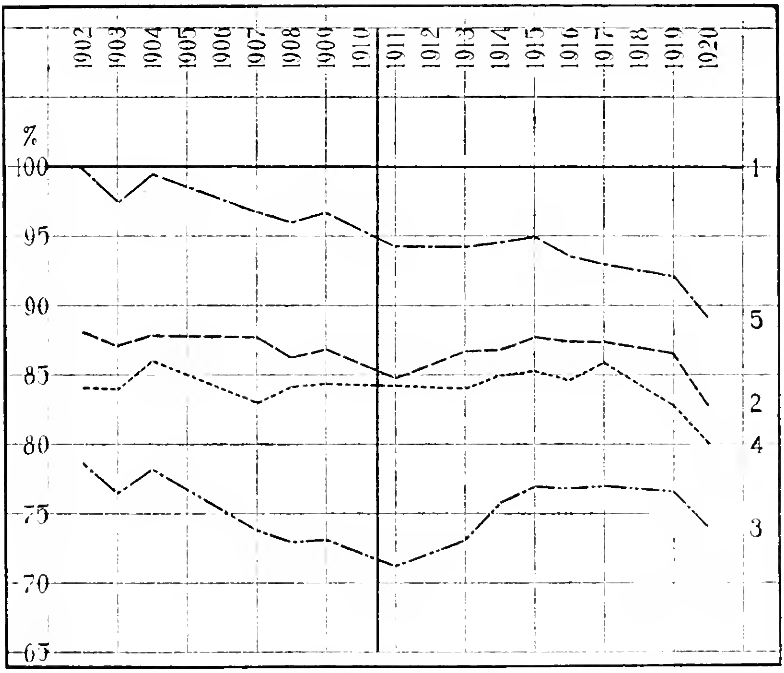


FIG. 2. — Relative trunk circumferences. Circumferences on plot 1 taken as 100 per cent. Plot numbers are shown at the right.

Varietal Response to Treatment.

Turning now to the question of whether all varieties have responded in the same manner to the various fertilizer treatments, we may examine Fig. 3. This shows the average trunk circumferences of the four varieties at three periods: first, in 1902, at the end of the period of hay removal; second, in 1911, at the end of the sod mulch period; third, in 1919, after nine years of partial or strip cultivation.

An examination of these graphs shows that the several varieties have maintained about the same relative positions during the entire period for which growth records have been kept. With increased size of the trees, the absolute differences have naturally increased. Rhode Island Greening has done better on the manure and ashes plots than on the other three

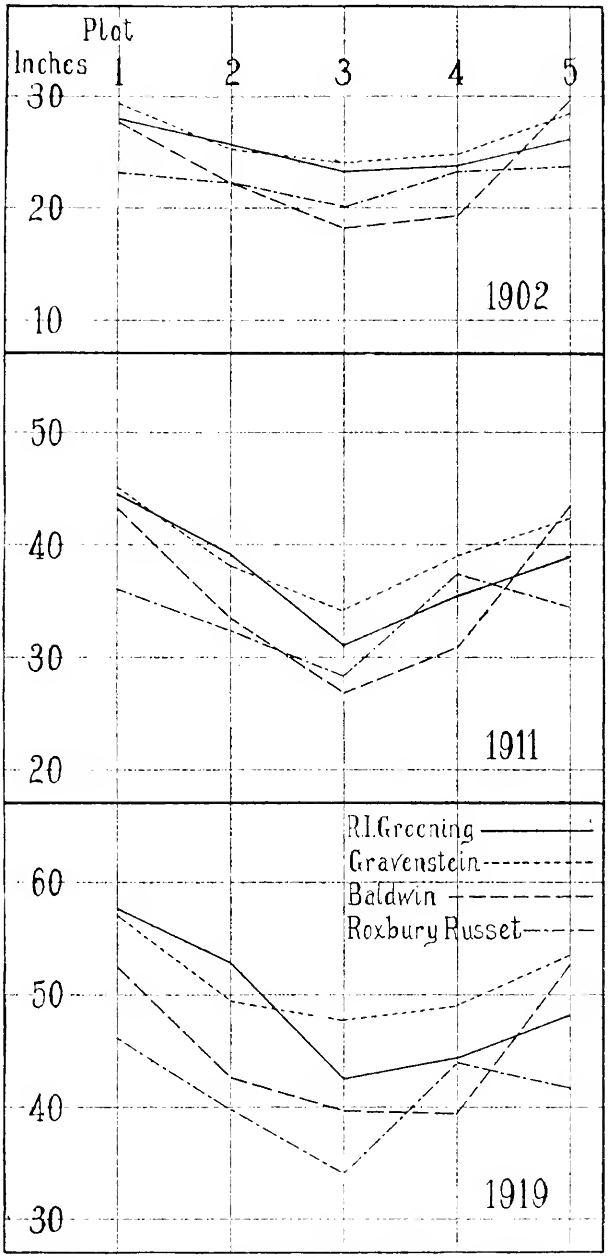


FIG. 3. — Trunk circumferences by varieties. Figures across top are plot numbers.

plots. Roxbury Russet is larger than Baldwin on the muriate plot, and the opposite is true on the sulfate plot, the differences here being quite marked and increasing with the age of the trees.

On the manure plot Rhode Island Greening has gained on the other varieties, which may be due to the fact that it is the outside row with free exposure to the north. On the ashes plot no relative change of the four varieties appears. On the check plot Baldwin has gone ahead of Roxbury Russet during the period of strip cultivation. Gravenstein has increased its lead over the other varieties, especially during strip cultivation. On the sulfate plot Gravenstein has gone ahead of Baldwin during the strip cultivation period, while the other varieties have maintained very much the same relative positions.

While there seem to be some quite marked varietal differences in growth, notably in the Baldwin and Russet on the two potash plots, it would be unsafe to conclude that they are due to the fertilizer treatments. They may be in part, but it is more likely that disease, natural soil differences, or inherent differences in the stocks used may be responsible.

Yield Records.

In Table 1 are given the total yields by plots and by varieties for the periods when no cultivation was practiced, and for the later period of strip cultivation.

TABLE 1. — *Total Yields by Varieties and by Plots (Pounds).*

VARIETIES.	Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Totals.
R. I. Greening:						
Before 1912	11,043	5,420	1,471	5,062	5,091	28,087
1912–20	16,989	14,310	7,344	10,367	9,881	58,891
Totals	28,032	19,730	8,815	15,429	14,972	86,978
Roxbury Russet:						
Before 1912	7,832	4,930	1,652	6,010	7,375	27,799
1912–20	12,123	7,620 [1]	4,554	6,954 [2]	8,397	39,648
Totals	19,955	12,550	6,206	12,964	15,772	67,447
Baldwin:						
Before 1912	8,168	4,155	735	2,359	10,936	26,353
1912–20	12,853	10,225	3,515 [3]	5,234	12,616	44,443
Totals	21,021	14,380	4,250	7,593	23,552	70,796
Gravenstein:						
Before 1912	4,308	2,697	1,490	4,412	4,035	16,942
1912–20	3,839 [4]	5,855	5,289	7,175	5,175	27,333
Totals	8,147	8,552	6,779	11,587	9,210	44,275
All varieties:						
Before 1912	31,351	17,202	5,348	17,843	27,437	99,181
1912–20	45,804	38,010	20,702	29,730	36,069	170,315
Totals	77,155	55,212	26,050	47,573	63,506	269,496

[1] One tree died in 1919.
[2] One tree died in 1907.
[3] One tree died in 1913.
[4] One tree died before 1907, and one in 1919.

The yields have been light, averaging only about 2¼ barrels per year per tree for the period from 1912 to 1920, inclusive, when the trees were practically mature. Rhode Island Greening has been the heaviest producer, deriving its superiority largely from plots 1 and 2. Baldwin is second, due in part to its superiority on plot 5. Roxbury Russet is third, and Gravenstein fourth, this variety being considerably inferior to the others in yield.

In total yields of all varieties by plots, the order is the same as for the size of the trees measured by trunk circumference. Plot 1 is ahead, followed by plots 5, 2, 4 and 3 in order.

All varieties increased their yield strikingly in the second period on nearly all plots, and especially on plot 3, the unfertilized plot. Here the total yield of all varieties was nearly fourfold. Baldwin increased nearly fivefold despite the loss of one of the three trees in 1913. On plot 1 the increase of all varieties was a little less than 50 per cent, though the yield of Gravenstein fell off, owing to the death of one tree before 1907, and the decline and death of another in 1919. If we assume that the normal increase due to growth of the trees is about 50 per cent, then plot 3 has increased its yield about two and one-half times over its normal, while the increase on plot 2 was about 40 per cent more than this assumed normal increase. Plot 4 has increased slightly more than the normal, while plot 5 has failed to make the normal gain.

There are several suggestive things that can be noted concerning the response of the different varieties to strip cultivation, but the small number of trees involved makes it rather doubtful if these differences have real significance.

The total yield of apples from the five plots from 1902 to 1920, inclusive, is shown graphically in Fig. 4. The heavy crops have been in the odd years, and are shown by heavy lines, while the light yields of the even years are shown by the lighter lines. The heavy perpendicular line between 1910 and 1911 marks the transition from sod mulch to strip cultivation.

This chart shows that in the off years there were no very great nor consistent differences between the plots until the 1920 crop. Nor has there been a very great increase in yield with the larger size of the trees in succeeding years. The off-year crop on the unfertilized plot has been the lowest of all in most years until the last two crops, when it has been about the average of the whole orchard. This better showing probably is the result of the increased growth of these trees since strip cultivation has been practiced. The crop of 1920 was heavier than that in any other off year, and, together with the light crop set in 1921 at the time of this writing, may mark a reversal of the off and on years. In 1920 the crops on the several plots were in much the same order as in the on years.

The off-year yields of the muriate and sulfate plots have been closely parallel, and the same is true of the on-year yields, yet the yields of the muriate plot have been distinctly inferior to those of the sulfate plot. This difference is less since 1911 than before, and may be due merely to

the smaller size of the trees. The manure plot has been the best producer in most years, and its superiority seems to have increased in the last three on-year crops. The ashes plot has approached the manure plot more closely since 1911 than before. The unfertilized plot has been, up to 1920, far in the rear of all the fertilized plots, though showing material gains in on-year yields since 1911, which brought it slightly above the muriate plot in 1919.

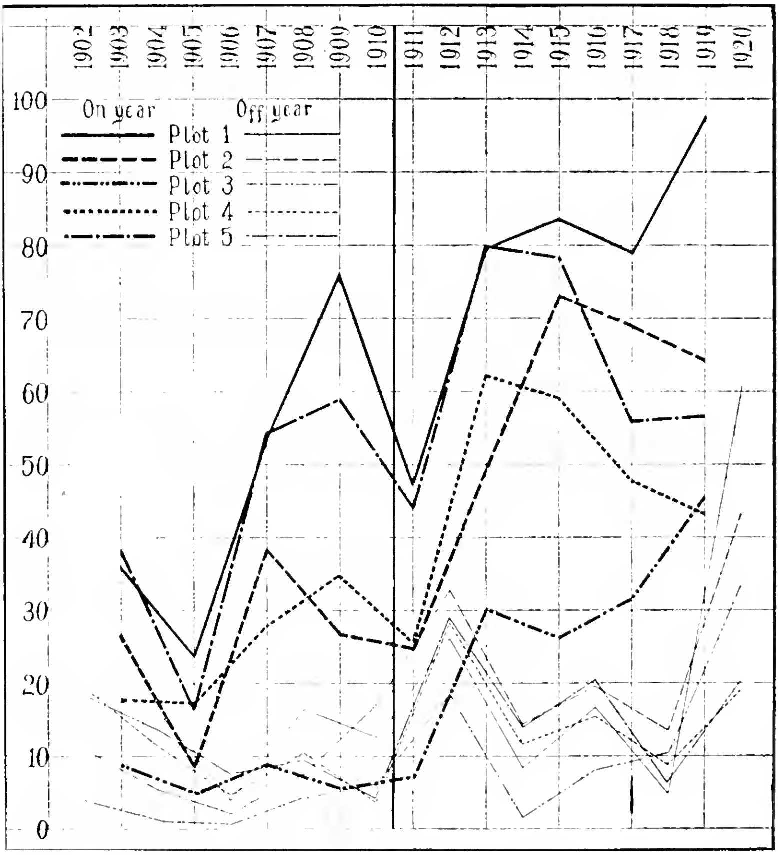


FIG. 4. — Total yields by plots in hundreds of pounds. The odd numbered years are the bearing or "on" years. Figures at left are hundreds of pounds.

It is apparent that the effect of the manurial treatment on yield has been slight in the off years, but in the on years it seems reasonable to conclude that there have been differences in yield due to the different manurial treatments. These differences in the on years follow closely the differences in growth of the trees. It is probable that the fertilized plots have exceeded in yields the unfertilized plot mostly because the trees were larger. The fertilized plots have received greater or less supply of nitrogen.

Many experiments have shown that abundant nitrogen favors the set of fruit. There is also no doubt that on these plots the fruit has been larger than on the unfertilized plot. These additional factors would contribute to the increased yield of the trees on the four fertilized plots. Inasmuch as the trees on the unfertilized plot now approach those of the other plots in size, it is probable that this inferiority would be somewhat less marked in the future were the treatment to be continued as in the past.

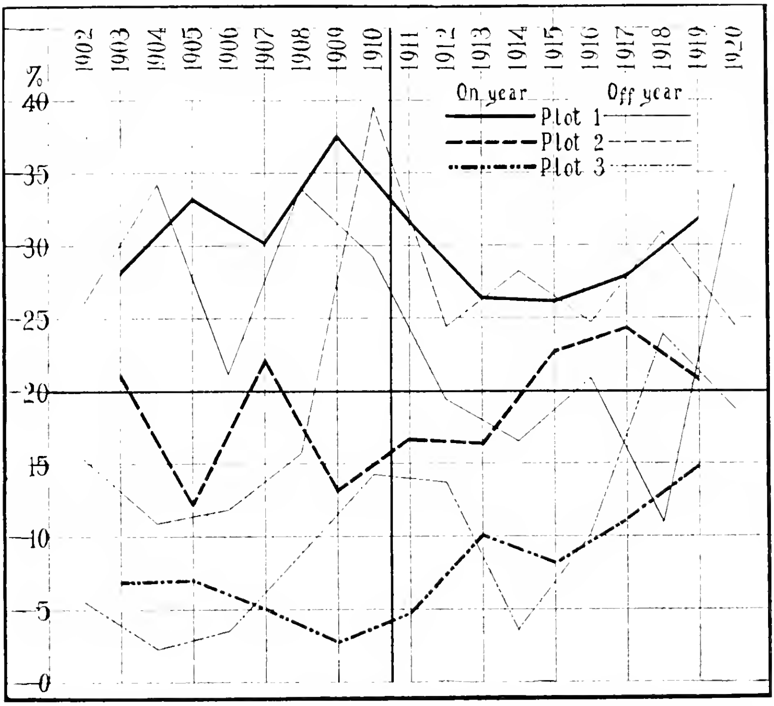


FIG. 5. — Yields by plots in percentages of total yields of the whole orchard. Plots 1, 2 and 3.

It was observed that the ashes, muriate and sulfate plots produced considerable growth of clover while fertilizer applications were kept up. When these ceased in 1916 the clover gradually disappeared. No doubt this growth of clover contributed nitrogen to the trees. The decline in growth and production of these three plots during the last four or five years may have been in some measure due to this lessened nitrogen supply.

The relative yields of the five plots are shown from another viewpoint in Figs. 5 and 6, where the yields are shown in percentages of the total crop of the whole orchard. Fig. 5 shows plots 1, 2 and 3, and Fig. 6 shows plots 4 and 5. Here, again, the heavy lines show the on-year yields and the light lines the off-year yields. Inasmuch as there are five plots, the

horizontal line along the abscissa of 20 per cent shows what we may call the normal yield of each plot.

The manure plot produced from 8 to 17 per cent excess over its normal 20 per cent under sod mulch in the on years, and only a little smaller excess in the off years. Under strip cultivation since 1910 it has fallen to an average excess of about 8 per cent in the on years, and in three of the off years it has failed to produce its normal 20 per cent of the crop. Of course this percentage loss of the manure plot is made up by the other plots, and the ashes plot has helped do this. In all but two of the on years under sod mulch it failed to produce its normal 20 per cent, while in three out of five crops under strip cultivation it has exceeded its normal share. In the off years since strip cultivation its excess is much more marked. The unfertilized plot was far behind under the sod mulch system, but shows fairly consistent gains since strip cultivation has been practiced, and in one of the off years has exceeded its normal 20 per cent.

Effect of Form of Potash. — The muriate and sulfate plots have usually been in close accord in the off years, but in the on years there was marked superiority in the sulfate plot up to and including 1911, with the exception of 1905. Since 1911 the yields of these two plots have not differed widely.

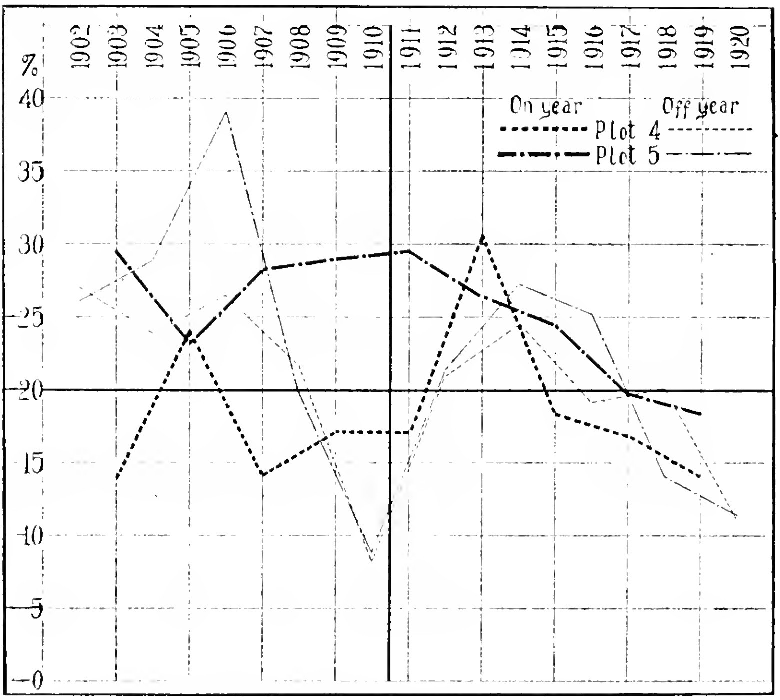


FIG. 6. — Yields by plots in percentages of total yields of the whole orchard. Plots 4 and 5.

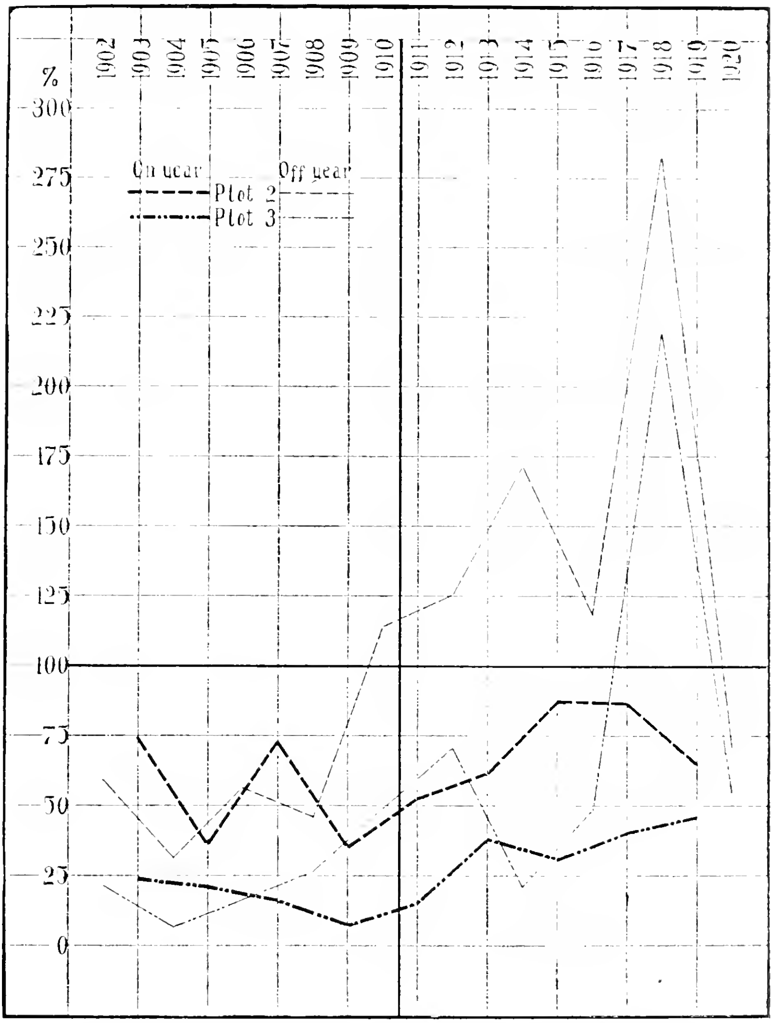


FIG. 7. — Relative yields of plots 1, 2 and 3. Yields on plot 1 taken as 100 per cent.

Whether the wide differences of the crops of 1903, 1907, 1909 and 1911 were accidental, or were due to the different fertilizers used on the sod mulch system then practiced, it is impossible to say. It seems certain that no significant differences have appeared since 1911, and of course the buds for that crop were formed while the plots were handled under the sod mulch system. Both these plots have, since 1913, produced a steadily decreasing proportion of the crop of the orchard.

Still another view of the plot yields is shown in Figs. 7 and 8, which show the yields of plots 2, 3, 4 and 5, with plot 1, the manure plot, taken

as 100. These figures show clearly how plot 1 has often been exceeded by the other plots in the off years and scarcely at all in the on years. The increased production of the ashes and unfertilized plots since strip cultivation was begun is shown. The relative decrease of the ashes and unfertilized plots under sod mulch is shown, and also their gain on the manure plot when strip cultivation was begun. The unfertilized plot still continues a relative increase, while the ashes plot shows a falling away in the last few years. Fig. 8 shows clearly the parallel courses of the muriate and sulfate plots, with a relatively wider difference under sod mulch, and a gradual convergence since strip cultivation has been practiced.

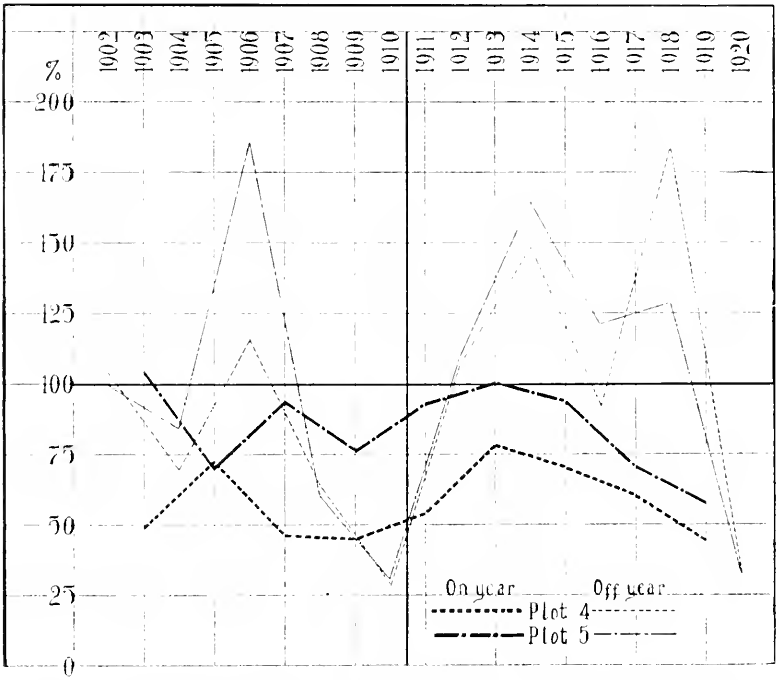


FIG. 8. — Relative yields of plots 1, 4 and 5. Yields on plot 1 taken as 100 per cent.

Correlation between Growth and Yields.

It is interesting to compare these graphs with Fig. 2 showing similar measures of growth as indicated by trunk circumference. Several investigators have shown a close correlation between growth and fruit production. Within limits the two go together, — the more growth the greater fruit production. This conclusion is supported by a comparison of Fig. 2 with Figs. 7 and 8. Especially do the lines representing growth and production

on the unfertilized plot show a general resemblance, both falling off under sod mulch and rising when strip cultivation was begun. There is only a little less striking resemblance in the curves for the other three plots.

Quality.

Considerable differences in quality of the product of the several plots have appeared. This is considered to include size, color, keeping quality and dessert quality. No special records of size have been kept, but observation shows that differences in size have been closely correlated with yield; the apples on plot 3 have been small and those on plot 1 generally larger than those of any other plot. Rarely has the crop on any tree been large enough to limit the size of the fruit.

Brooks[1] reports near the end of the sod mulch period: —

In color and general attractiveness of appearance the fruit of the several plots has usually ranked in the following order: plots 2, 5, 4, 1 and 3. In the early years of the experiment the rank of the fruit in size was in the order: plots 5, 4, 1, 2 and 3. At the present time (1909) the apples on plot 1 take a higher relative rank and in all cases where the quantity of fruit is not excessive the apples on plot 1 are usually larger than on any of the other plots.

A number of tests of keeping quality have been made, and in this respect the fruit has usually ranked in about the following order: plots 5, 4, 1, 2 and 3. The relatively low rank of the fruit from plot 2 in keeping quality appears to be connected with the fact that this fruit comes to maturity earlier than that on the other manured or fertilized plots. It will be noted that the fruit from plot 2 ranks highest in appearance. This is due to its superiority in coloring. This in turn is undoubtedly connected with the fact that the fruit is somewhat more mature. Such fruit might undoubtedly be kept if promptly put into cold storage; but in ordinary storage it is considerably inferior to the somewhat less thoroughly ripened fruit on the other manured plots.

The fruit from plot 5 has almost invariably been much superior in appearance to that produced on plots 1 or 4. Here again there have been individual variations in the product of the different trees of the same variety on all of the different plots. There has, however, been no doubt as to the fact that on the whole the product of plot 5 has been considerably superior in color and general attractiveness as well as in firmness of flesh to the product from plot 4; while the product from plot 1, which receives barnyard manure, ranks below either of the others in the qualities just mentioned. In general, the fruit produced on plot 5 shows a considerably brighter and clearer color than that on either plots 4 or 1. There can be no doubt that it would sell at a higher price in the general market than either of the others, although the difference between plots 4 and 5 is considerably less than between plots 1 and 5. The product of the unmanured plot, 3, shows good color and in some cases is of fair size, but in general is too small to command the best prices.

At the present time, after ten years of strip cultivation, these differences between the several plots are not as marked as during the sod mulch period, yet they continue in considerably reduced degree.

[1] Mass. Agr. Expt. Sta., Ann. Rept. 22, Pt. 2, p. 14 (1910).

The Graves Orchard.[1]

As the experiment above reported progressed, marked differences appeared between plots 4 and 5, the muriate and sulfate plots. Though these differences became less in later years, in 1907 they appeared important enough to justify further investigation. Accordingly a ten-year lease of a young Baldwin orchard, located in the southeastern part of the town of Amherst about six miles distant from the Experiment Station, was secured.

An experiment was planned to show whether differences similar to those which had appeared between plots 4 and 5 would appear here also, and whether, if such differences did appear, they were due to the form of the potash, which was muriate in one case and sulfate in the other, or to the presence of magnesium in the low-grade sulfate of potash.

The site of the orchard was a gentle northeasterly slope, with the steep slope of the easterly end of the Holyoke mountains about 40 rods to the south. The soil was a medium sandy loam rather low in fertility.

The trees, with the exception of four scattered trees, were of the Baldwin variety, and were said to be six years old at the beginning of the experiment. While most of the trees were fairly uniform at the start, there were a number of poor stunted trees which died or were replaced with new trees early in the experiment. None of these young trees bore fruit during the experimental period, and they are omitted in the consideration of the results. A plan of the orchard is shown in Fig. 9.

The orchard was in sod when taken over, but it was plowed in the spring of 1908, and in the following years handled in a system of cultivation and non-leguminous cover crops. As shown in the plan a strip on the north end was left in sod during the whole period.

Fertilizer Treatment.

In the spring of 1908 the orchard was laid out in eight plots of two rows each, and application of fertilizers made as shown in Fig. 9. Application of these materials at the given rates was made annually during the first half of May, beginning in 1908 and continuing for six years. In 1914 the applications to row 2 of each plot were discontinued, and the amounts given to row 1 of each plot reduced to one-half the former amounts. This plan was followed for four seasons until the expiration of the lease ended the experiment.

The circumference of the trunks 1 foot from the soil was taken in the spring of 1908; in April, 1914; in April, 1916; in November, 1917; and in August, 1921.

The first crop of fruit was produced in 1911. This was followed by a very light crop in 1912 and moderate crops in 1914, 1915, 1916 and 1917. Yield records were taken by plots, omitting the four odd trees mentioned

[1] This experiment was planned by Dr. Wm. P. Brooks, then director of the Experiment Station. The data were taken under the direction of Prof. F. C. Sears and E. F. Gaskill. The writer is responsible for the tabulation and interpretation of the data.

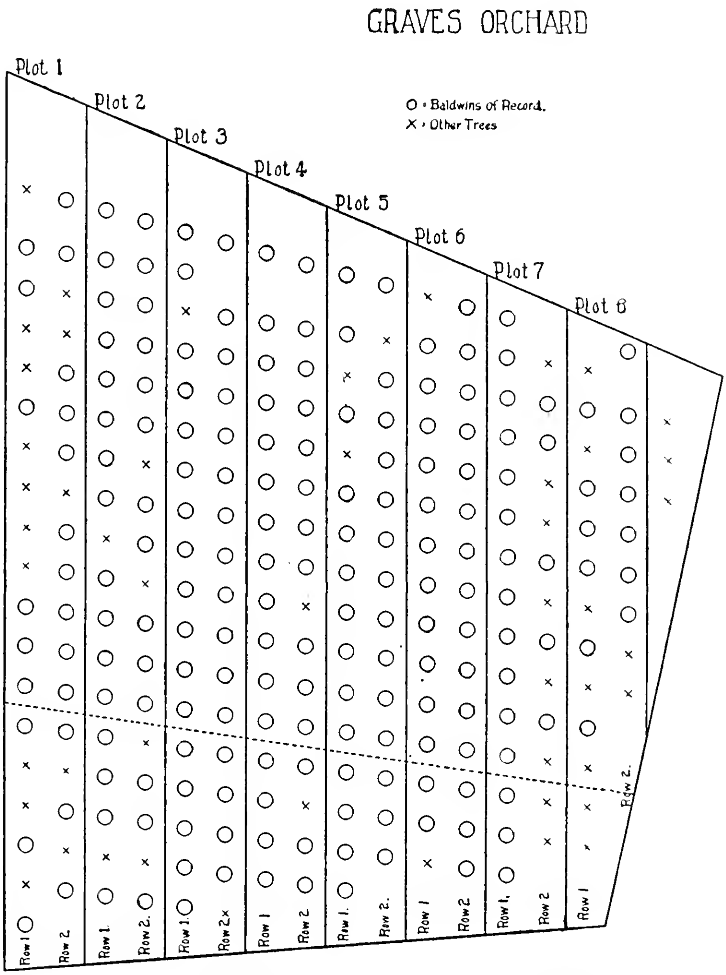


FIG. 9. — Plan of the Graves orchard. The portion below the dotted line was in sod.

Fertilizer Treatment per Acre.

Plot 1.	Manure	8 tons
Plot 2.	Ashes	1,600 pounds
Plot 3.	No fertilizer.	
Plot 4.	Bone	600 pounds
	Muriate of potash	160 pounds
Plot 5.	Bone	600 pounds
	Low-grade sulfate of potash	320 pounds
Plot 6.	Bone	600 pounds
	Muriate of potash	160 pounds
	Sulfate of magnesia	255 pounds
Plot 7.	Bone	600 pounds
	High-grade sulfate of potash	160 pounds
Plot 8.	Basic slag	800 pounds
	Low-grade sulfate of potash	320 pounds

above. Individual tree records of yield were not taken, nor was any separation made of the yields of that portion of the trees remaining in sod. In the early years no separate record of dropped and picked fruit was made, but in the last four years the picked fruit was recorded separately.

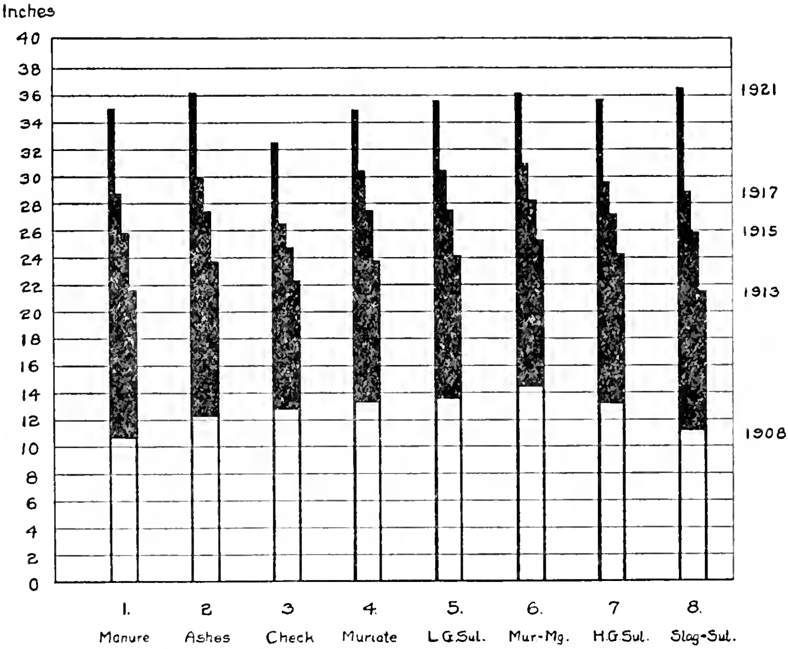


FIG. 10. — Average trunk circumference by plots, cultivated Baldwin trees only (Graves orchard).

Growth Records.

Fig. 10 shows the increase in trunk circumference of the trees in cultivation in the several plots. The growth on plot 3, the check plot, has been less than on the other plots, indicating that the trees responded to the application of all the fertilizers by increased growth. At the beginning of the experiment the trees on plot 3 were exceeded in size by those on plots 4, 5, 6 and 7. In 1917, at the end of the period of fertilization, this difference had increased somewhat, while the trees on plots 1, 2 and 8 had grown so that the check plot then had the smallest trees of any plot. A later measurement of the same trees made in August, 1921, showed that the check trees were still the smallest. It is interesting to note that plots 1, 2 and 8 are the only plots that showed greater growth than the check plot in this four-year post-experimental period.

One seems justified in concluding that on these Baldwin trees under cultivation the fertilizer applications have caused greater growth, and that manure and lime-carrying fertilizers have been more beneficial than those chemical fertilizers which carried no lime.

As has been stated, there was a strip across the north ends of the plots that remained in sod during the entire experimental period. The trees on this strip made considerably less growth than those in cultivation, as shown in Table 2.

TABLE 2. — *Average Increase in Trunk Circumference, 1908–17.*

Plot.	Treatment.	Trees in Sod.		Trees in Cultivation.	
		Number.	Increase in Circumference.	Number	Increase in Circumference.
1	Manure	6	15.2	16	18.1
2	Ashes	7	14.5	24	17.6
3	No fertilizer	9	11.0	25	13.7
4	Bone and muriate	7	12.6	23	17.2
5	Bone and low-grade sulfate	9	12.1	21	16.9
6	Bone, muriate and magnesia	7	12.8	23	16.4
7	Bone and high-grade sulfate	4	14.5	17	16.4
	Averages and totals	49	13.3	149	16.6

The trees on plot 7 made relatively more growth in sod than those on the other fertilized plots, but owing to the small number of trees involved there is a question if the difference is significant. With this one exception the two series of plots parallel each other very closely. The parallel between plots 4 and 5 is very close. As previously stated, there was some indication that in the station orchard, under sod or sod mulch conditions, low-grade sulfate of potash was superior to muriate. In this orchard, what slight difference there is is reversed in both the sod and cultivated portions of the plots.

It has been stated that in 1914 and following years row 2 of each plot received no fertilizer, while row 1 of each plot received only one-half the amounts previously applied. Table 3 shows the average increase in trunk circumference of the trees in cultivation; no dependable comparison can be made of those in sod because of too few trees.

TABLE 3. — *Average Trunk Circumference of Trees in Cultivation, All Plots except Check (Inches).*

Row.	Treatment.	1913.	1915.	1917.
1	One-half previous amounts	23.50	27.26	30.19
2	No fertilizer	22.94	26.68	29.24
	Difference	.56	.58	.98

These figures indicate a slight response in circumference increase apparently due to the fertilizers, but not enough to be of much significance.

Yield Records.

The yield records of this orchard have been kept by plots only. Inasmuch as the plots are of different sizes and include different numbers of trees, it seems best to divide the total plot yields by the number of bearing trees, thus obtaining the average yield per tree. The average total yield per tree is shown in Table 4.

TABLE 4. — *Average Yields per Tree (Pounds).*

Plot.	Treatment.	1911.	1912.	1914.	1915.	1916.	1917.	Average.
1	Manure	92	15	117	224	328	158	156
2	Wood ashes	217	44	211	221	316	133	191
3	No fertilizer	234	67	101	188	102	223	153
4	Bone and muriate	188	38	66	390	213	268	194
5	Bone and low-grade sulfate	114	55	334	212	347	141	201
6	Bone, muriate and magnesia	251	58	418	195	332	191	241
7	Bone and high-grade sulfate	279	45	338	260	200	159	214
8	Slag and low-grade sulfate	163	11	334	175	387	221	215

The lowest yield is from the unfertilized plot, 3, and the highest yield is from the muriate and magnesium plot, 6. Plots 4 to 8 show rather uniform yields, varying from 194 to 241 pounds per tree, and it is probably unsafe to attribute the differences that do show to the differential fertilizer treatment. The yield from the ashes plot (189 pounds) is only a little below that of these plots, and may or may not indicate that this fertilizer treatment was less effective in producing apples than the treatments given to plots 4 to 8. The yield on the manure plot is low and may indicate an inferiority of manure as fertilizer on this soil, yet it should be noted that these trees were at first the smallest in the orchard, and at the end of the experimental period were exceeded in trunk circumference by all except those on the unfertilized plot. Plots 4 and 5 received practically the same fertilizer treatments as plots 4 and 5 in the station orchard, the results from which this experiment was planned to explain. The difference in yield is here only 7 pounds per tree, a degree of similarity rarely secured from plots receiving identical fertilizer treatments.

Fig. 11 shows the average yield per tree by two-year periods, — 1911 and 1912, 1914 and 1915, and 1916 and 1917, — there being no crop in 1913. The most significant fact brought out here is that the unfertilized plot shows practically the same yield for each period, while the fertilized plots all show substantial gains for the second two periods over the first. The slag-sulfate plot, 8, shows a large gain, and the manure plot, 1, makes

a better showing from this viewpoint than from that of average total yields per tree. The ashes plot, 2, made a substantial gain during the second period, but made little further gain in the third period.

It seems reasonable to conclude that under the conditions at this orchard, which is on a sandy soil of inferior fertility, as indicated by the growth of cover crops and other herbaceous plants, the fertilizers applied have been beneficial to the trees, as indicated by increased growth and greater production.

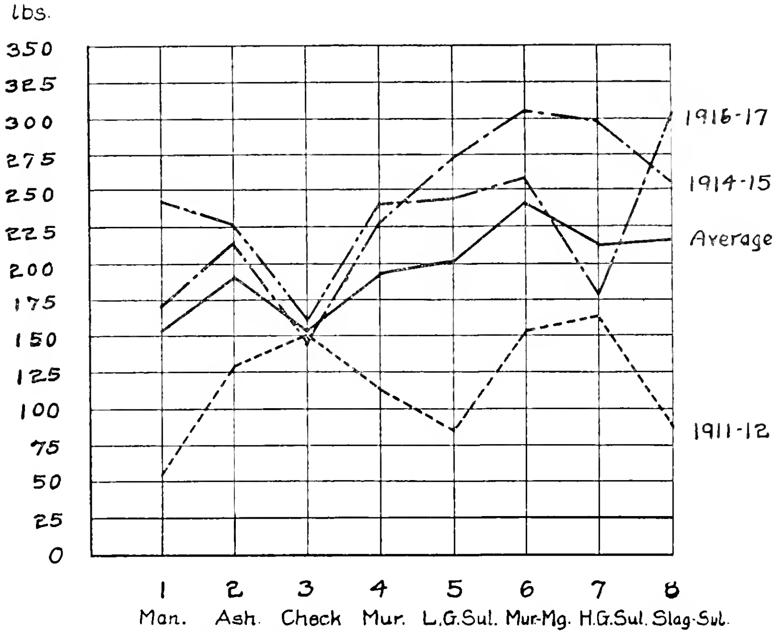


FIG. 11. — Average yield per tree by two-year periods (Graves orchard).

Discussion of Results.

The results of many orchard fertilizer experiments in this country have shown that, of all the fertilizer elements usually taken into consideration, nitrogen is most likely to produce a response. This response appears in darker colored and more luxuriant foliage, more growth, and often increased production of fruit. It may be worth while to consider how far the observed results, especially those of growth, can be explained on the basis of variation in available nitrogen supply.

The manure plot in the station orchard has plainly responded to the generous supply of nitrogen it has received. Growth, foliage color, and size and color of fruit have all been typical of trees well supplied with nitrogen. Both the potash plots in this orchard have received small supplies of nitrogen in the ground-bone application of 600 pounds per

acre. This amount of bone supplies only about one-tenth as much nitrogen as plot 1 has received, and yet it is doubtless enough to account in part, at least, for the greater growth than that observed on the unfertilized plot. The uniformity of the several potash plots in the Graves orchard indicates that this may have been a nitrogen response rather than one to potash. All indications are that the Graves orchard soil is deficient in nitrogen, and a small supply of this element might be expected to produce marked results.

The relatively strong growth of the trees on the ashes plots and on the slag-sulfate plot in the Graves orchard indicates that added nitrogen cannot wholly account for the greater growth of the fertilized trees. Probably the presence of lime has favored greater availability of the nitrogen-carrying humus, even though this may have been present in only small amount in this soil, and so operated to increase the nitrogen available for the trees. The striking response to cultivation of the trees on the unfertilized plot in the station orchard may be fairly taken to indicate that lime is not always necessary to render the humus nitrogen available.

Manure has had a more persistent residual effect in both orchards than the other materials used. Evidently the effect of greater nitrogen supply because of cultivation, on plots not receiving manure, lasted about five years, after which the nitrogen supply was insufficient to maintain the increased growth of the trees.

The fact of inferior growth and production of the muriate plot in the station orchard as compared with the low-grade sulfate plot is interesting, and seems to have been peculiar to sod mulch management. Its inferiority apparently disappeared when the soil was cultivated. There is no evidence of such a difference on the lighter, better-drained soil of the Graves orchard. It is probable that this superiority of the low-grade sulfate was a real one. It has been suggested that the difference was due to the poorer drainage of the muriate plot. But the adjoining unfertilized plot is still more inferior in this respect, and yet this plot gave very good results when strip cultivation was adopted. It has been shown that muriate of potash may exert a depressing effect on nitrification, and this may possibly explain the results obtained. The attempt to explain whether this difference was due to the difference in the form of potash or to the presence of magnesium in the low-grade sulfate was unsuccessful, as no significant differences were obtained in the Graves orchard even with the trees in sod. The Graves orchard received a lighter application of potash and for a shorter period of years. Possibly this may have been a factor in bringing about different responses.

Summary.

1. In the two orchard experiments here reported, growth and fruit production were closely correlated. Increased growth was followed by increased production.

2. In one of the orchards, trees in cultivation gave better growth and higher production than when in sod.

3. In a sod orchard, low-grade sulfate of potash gave better results than muriate of potash, both plots receiving also ground bone. With strip cultivation this difference seemed to disappear. In a cultivated orchard, on lighter, better-drained soil, no significant differences appeared. On the sod portion of this second orchard, furthermore, there were no material differences.

4. The residual effect of manure was greater than that of ashes or the chemical fertilizers used.

APPENDIX.

Here are given the original data on which the discussion in this paper is based.

Table I. — *Station Orchard: Tree Circumferences (Inches).*

Rhode Island Greening.

Tree.	Plot 1.			Plot 2.			Plot 3.			Plot 4.			Plot 5.		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1902[1]	Av. 28.0			Av. 25.5			Av. 23.2			Av. 23.7			Av. 26.2		
1903[1]	Av. 30.3			Av. 27.0			Av. 23.6			Av. 25.9			Av. 27.0		
1904[1]	Av. 33.0			Av. 29.8			Av. 26.1			Av. 28.2			Av. 30.8		
1907	36.5	34.3	38.8	33.5	29.5	37.0	26.5	20.8	34.3	30.0	23.0	35.5	29.0	34.5	34.0
1908	39.0	38.0	41.0	35.0	30.8	39.3	28.0	21.5	35.8	31.5	25.0	37.0	31.5	36.5	37.0
1909	40.5	40.0	42.5	36.5	32.0	40.8	28.5	21.5	36.8	32.5	26.5	38.5	32.5	38.5	37.8
1911	44.0	44.3	45.5	38.5	35.0	43.8	30.5	23.3	39.5	35.5	29.8	41.3	35.0	41.8	40.3
1913	46.0	48.5	48.0	42.5	37.0	47.5	32.0	25.0	43.0	37.5	32.0	43.3	36.0	42.5	44.0
1914	48.0	49.5	49.3	44.5	38.5	49.8	33.8	26.0	44.3	38.8	33.8	44.8	36.8	44.5	46.0
1915	49.3	52.3	51.3	46.8	40.0	51.3	36.0	27.5	46.5	40.0	35.8	46.0	38.3	45.0	47.5
1916	52.3	55.5	54.0	49.5	42.0	54.0	37.5	29.3	49.5	42.0	37.5	48.0	39.8	47.3	50.0
1917	52.5	55.5	54.0	50.0	42.3	55.0	38.3	30.3	49.8	42.3	38.0	48.0	40.0	47.5	50.0
1919	56.0	59.5	57.8	54.3	46.8	57.5	40.5	32.8	53.0	43.0	40.5	49.5	42.0	50.0	53.0
1920	57.5	59.8	58.5	55.5	45.8	58.3	41.3	33.5	53.5	44.0	41.5	50.8	43.0	51.5	54.5

Roxbury Russet.

Tree.	Plot 1.			Plot 2.			Plot 3.			Plot 4.			Plot 5.		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1902[1]	Av. 23.2			Av. 22.3			Av. 20.0			Av. 23.3			Av. 23.8		
1903[1]	Av. 24.0			Av. 23.0			Av. 20.4			Av. 24.0			Av. 24.8		
1904[1]	Av. 26.8			Av. 25.0			Av. 22.6			Av. 26.4			Av. 26.9		
1907	30.0	29.5	30.0	27.5	28.5	27.0	21.0	26.0	24.0	28.8	33.5	23.3	30.5	29.5	28.0
1908	32.0	31.5	30.5	28.5	29.5	28.3	22.0	27.5	25.5	30.0	35.0	23.3	32.0	30.8	29.8
1909	32.8	32.8	32.8	29.8	30.5	29.3	22.5	28.5	26.8	31.0	36.3	[2]	33.0	31.8	30.5
1911	35.0	36.0	37.0	32.5	32.8	32.0	24.5	31.3	29.0	34.8	40.0		35.5	34.0	33.5
1913	37.8	38.8	39.5	34.5	34.5	33.0	25.5	33.0	31.0	36.5	41.3		37.0	36.0	35.0
1914	39.3	40.3	40.5	35.8	35.5	34.0	28.8	33.5	31.8	37.8	45.3		38.0	37.3	36.0
1915	40.5	41.3	41.5	37.0	37.0	36.0	28.0	34.5	32.5	39.5	43.8		39.8	38.5	37.5
1916	42.5	43.0	44.0	38.5	38.8	37.5	28.8	36.3	33.3	40.5	45.0		40.5	39.8	39.0
1917	42.5	43.0	45.0	38.5	38.8	37.5	29.0	36.3	33.5	40.5	45.0		40.8	40.0	39.0
1919	45.5	45.3	47.5	40.5	40.3	39.0	30.3	37.3	35.0	42.3	46.0		42.8	42.3	40.5
1920	47.3	46.8	48.5	[2]	41.0	39.8	31.0	37.8	36.0	43.3	47.8		43.8	43.3	41.8

[1] Measurements of individual trees for these years not available. [2] Tree died.

TABLE I. — *Station Orchard: Tree Circumferences (Inches)* — Concluded.

Baldwin.

Tree.	Plot 1.			Plot 2.			Plot 3.			Plot 4.			Plot 5.		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1902 [1]	Av. 27.7			Av. 22.3			Av. 18.2			Av. 19.3			Av. 29.8		
1903 [1]	Av. 29.1			Av. 23.3			Av. 19.0			Av. 20.3			Av. 31.2		
1904 [1]	Av. 32.5			Av. 25.9			Av. 21.4			Av. 23.1			Av. 34.3		
1907	36.5	36.0	34.0	28.8	25.5	31.3	24.8	23.5	19.8	21.5	30.0	23.5	38.0	33.0	40.3
1908	39.5	39.0	36.0	30.0	27.5	32.8	25.5	25.5	21.0	23.0	32.0	25.3	40.0	34.5	42.8
1909	40.5	40.0	36.5	31.0	28.3	34.0	26.0	26.5	23.0	24.0	33.3	26.3	41.8	35.5	44.0
1911	44.0	44.8	41.0	33.0	31.3	36.0	28.0	29.0	23.8	27.8	36.5	28.5	45.3	38.0	47.5
1913	47.0	47.3	41.0	35.5	34.0	39.0	29.5	34.0	24.0	28.5	39.0	30.8	48.8	39.5	51.0
1914	48.0	48.5	42.3	37.0	35.3	40.0	30.8	35.5	[2]	29.8	40.0	32.0	50.5	41.0	52.0
1915	49.5	50.0	43.3	38.5	37.0	41.5	32.3	38.0		31.0	42.0	33.5	52.0	42.8	53.5
1916	51.5	52.5	45.0	40.0	39.0	43.0	33.5	40.3		32.5	43.5	35.3	53.5	43.3	55.5
1917	52.5	53.3	45.3	40.5	39.5	43.0	33.8	41.0		32.8	44.3	36.0	54.0	43.5	55.8
1919	54.8	56.5	47.0	42.3	41.5	44.5	35.5	44.0		34.8	46.3	37.5	56.0	44.8	58.0
1920	56.8	58.3	48.0	43.3	42.5	45.5	36.5	46.0		35.3	47.5	38.5	56.8	46.0	60.0

Gravenstein.

Tree.	Plot 1.			Plot 2.			Plot 3.			Plot 4.			Plot 5.		
1902 [1]	Av. 29.5			Av. 25.3			Av. 24.0			Av. 24.8			Av. 28.5		
1903 [1]	Av. 31.0			Av. 26.3			Av. 24.5			Av. 25.9			Av. 28.5		
1904 [1]	Av. 33.8			Av. 29.4			Av. 28.0			Av. 30.1			Av. 32.6		
1907	36.0	40.0	2.5	30.3	32.5	34.0	26.0	29.0	31.8	31.0	35.0	30.5	33.0	37.8	35.5
1908	39.3	42.0	3.5	32.0	34.0	35.8	27.0	30.8	34.0	32.5	37.5	32.3	35.0	39.5	37.3
1909	40.5	42.0	3.5	33.5	35.8	37.5	28.5	32.0	35.3	34.3	39.5	33.0	36.8	42.0	40.3
1911	43.8	46.3	7.0	36.0	38.5	40.3	30.5	34.5	37.3	37.5	43.5	36.0	40.3	43.8	43.0
1913	47.5	49.5	12.0	39.5	42.5	43.0	34.0	37.8	43.0	39.5	47.0	37.5	41.8	48.5	45.0
1914	48.0	52.5	12.0	41.0	43.8	44.3	35.3	39.3	44.8	41.5	48.0	38.5	43.5	50.3	46.8
1915	49.0	53.5	[2]	43.0	45.5	45.8	37.5	41.5	47.0	43.0	50.0	40.0	44.8	52.0	48.5
1916	50.5	56.5		45.0	47.8	47.5	39.0	43.0	50.0	45.0	52.3	41.3	46.0	54.0	50.5
1917	50.5	60.0		45.8	48.0	47.8	39.3	44.0	51.0	45.3	52.5	41.5	46.0	54.8	51.0
1919	50.0	64.0		48.0	50.3	50.0	42.0	46.8	51.5	47.3	55.5	44.3	48.5	59.0	53.3
1920	[2]	66.5		49.3	51.3	51.0	43.3	48.8	55.5	48.8	57.0	45.3	49.5	61.0	55.5

[1] Measurements of individual trees for these years not available. [2] Tree died.

TABLE II. — *Station Orchard: Total Yields by Plots (Pounds).*

Rhode Island Greening.

	Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Totals.
Before 1902	270	45	41	130	85	571
1902	777	272	65	521	260	1,895
1903	970	891	394	435	945	3,635
1904	972	139	34	566	297	2,008
1905	596	168	101	338	79	1,282
1906	274	39	27	419	52	811
1907	1,496	973	226	760	798	4,253
1908	948	232	85	328	270	1,863
1909	2,157	1,165	140	604	1,087	5,153
1910	806	334	84	146	101	1,471
1911	1,777	1,162	274	815	1,117	5,145
1912	864	922	811	1,220	747	4,564
1913	1,546	2,196	718	1,354	2,111	7,925
1914	325	194	93	259	189	1,060
1915	2,859	2,467	1,109	2,271	2,240	10,946
1916	761	338	378	188	210	1,875
1917	3,370	2,820	1,191	1,846	1,813	11,040
1918	123	226	135	124	76	684
1919	3,150	2,389	1,097	1,529	1,055	9,220
1920	3,991	2,758	1,812	1,580	1,440	11,581

TABLE II. — *Station Orchard: Total Yields by Plots (Pounds)* — Concluded.

Roxbury Russet.

	Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Totals.
Before 1902	269	119	39	251	291	969
1902	874	631	269	1,235	1,023	4,032
1903	703	567	330	608	1,067	3,275
1904	391	384	5	396	410	1,586
1905	548	206	165	621	769	2,300
1906	128	61	8	26	68	291
1907	1,361	1,295	313	903	1,389	5,261
1908	328	78	71	270	232	979
1909	1,719	547	90	991	1,172	4,519
1910	372	403	331	149	135	1,390
1911	1,139	639	31	560	828	3,197
1912	1,055	703	466	1,043	914	4,181
1913	1,963	1,128	754	1,629	2,390	7,864
1914	161	447	57	329	458	1,452
1915	2,398	1,984	400	1,311	2,066	8,159
1916	566	535	293	821	595	2,810
1917	1,942	1,455	345	802	1,045	5,589
1918	9	39	453	209	25	735
1919	2,839	922	1,057	722	753	6,293
1920	1,190	407	729	98	151	2,575

Baldwin.

	Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Totals.
Before 1902	151	43	3	46	475	718
1902	43	207	0	114	548	912
1903	1,043	705	55	228	1,400	3,431
1904	231	18	51	98	577	975
1905	1,024	277	43	165	474	1,983
1906	4	128	33	26	634	825
1907	1,718	1,102	189	561	2,514	6,084
1908	110	106	88	25	280	609
1909	2,590	695	132	682	2,443	6,542
1910	41	469	8	22	121	661
1911	1,213	405	133	392	1,470	3,613
1912	683	1,264	205	537	1,176	3,865
1913	2,546	655	663	514	2,017	6,395
1914	371	820	36	690	765	2,682
1915	2,425	1,381	354	637	2,389	7,186
1916	333	910	99	479	1,178	2,999
1917	2,125	1,145	412	695	1,694	6,071
1918	315	1,046	261	528	480	2,630
1919	3,430	2,040	1,425	1,148	2,835	10,878
1920	625	964	60	6	82	1,737

Gravenstein.

	Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Totals.
Before 1902	75	15	27	51	43	211
1902	196	3	65	91	57	412
1903	884	531	110	518	347	2,390
1904	44	10	22	84	103	263
1905	225	231	201	614	365	1,636
1906[1]	-	-	-	-	-	-
1907	775	482	162	572	709	2,700
1908	265	347	189	431	184	1,416
1909	1,180	284	224	1,217	1,192	4,097
1910	50	514	199	41	27	831
1911	612	282	291	793	1,008	2,986
1912	24	402	377	25	50	878
1913	1,922	976	897	2,736	1,474	8,005
1914[1]	-	-	-	-	-	-
1915	694	1,472	778	1,685	1,149	5,778
1916	16	199	79	54	50	398
1917	479	1,475	1,223	1,432	1,036	5,645
1918	37	53	209	26	39	364
1919	370	1,054	979	912	1,012	4,327
1920	297	224	747	305	365	1,938

[1] No crop.

Table III. — *Graves Orchard: Trunk Circumferences of Individual Trees (Inches).*

	Plot 1.		Plot 2.		Plot 3.		Plot 4.		Plot 5.		Plot 6.		Plot 7.		Plot 8.	
Row.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1908		6.3	10.0	8.0	14.5	11.5	9.5	11.0	12.0	17.0		10.0	10.0			
1913		11.0	19.5	16.5	22.3	19.8	17.8	18.8	20.5	29.6		17.3	17.0			
1915		13.8	23.5	20.5	24.5	23.0	22.5	22.0	23.8	33.5		17.8	19.0			
1917		16.8	25.8	24.0	25.5	25.0	26.5	24.0	25.5	36.0		19.5	20.5			
1921			32.0	30.5	31.5	30.8	30.8	28.5	33.0	44.0		24.5	24.8			
1908	6.0	9.0	7.3	14.0	14.0											
1913	14.8	18.0	18.1	27.9	24.9											
1915	19.0	21.5	22.5	31.5	27.5											
1917	23.5	24.5	25.8	34.0	30.0											
1921	29.5	30.0	33.0	38.5	36.0											
1908	10.0		14.0	15.0		12.5	13.5	15.0	2.8		11.5	13.0	14.5			10.0
1913	20.5		28.3	29.1		22.8	30.0	29.4	9.0		22.6	19.8	24.4			17.5
1915	24.8		32.0	33.5		25.8	33.3	33.0	13.5		27.5	21.3	26.5			
1917	28.0		34.0	35.5		28.0	37.5	36.0	18.3		30.0	23.5	29.0			23.0
1921	31.8		39.0	41.3		33.5	42.3	41.8	24.5		37.0	28.3	32.3			29.8
1908			11.5	8.0	12.5	11.5	12.0	11.0		10.0	17.0	10.0	18.0	11.0	17.0	11.0
1913			24.0	18.3	25.9	19.3	21.5	18.8		20.8	27.4	17.8	27.1	19.8	32.5	22.0
1915			28.0	22.0	28.8	21.0	24.8	21.5		24.0	30.8	20.0	30.5	22.8	37.5	26.5
1917			31.0	25.0	31.0	23.0	27.5	23.5		27.0	34.0	22.8	33.0	25.0	40.0	30.5
1921			37.0	29.5	37.5	27.5	31.3	27.8		30.5	40.0	27.0	37.5	31.5	48.8	37.0
1908		13.0	11.5	14.5	14.5	11.5	15.0	13.5	13.0	10.5	15.5	18.0	16.0	17.0		11.0
1913		25.3	26.1	29.0	26.5	16.3	25.1	25.0	22.0	20.9	28.4	31.0	28.8	28.8		23.5
1915		30.0	30.5	31.8	29.5	17.5	29.0	29.8	25.8	25.0	32.0	33.3	31.8	32.0		27.8
1917		32.8	33.3	34.0	31.0	18.3	32.0	32.0	28.3	26.5	34.0	37.5	34.0	34.5		30.5
1921		39.8	38.0	39.8	37.8	20.5	37.8	37.5	32.0	31.5	40.3	42.8	40.5	40.0		38.3
1908	8.8	11.0	9.0	13.0	13.0	10.0	12.0	15.0		17.0	12.5	16.0	16.0		15.5	8.5
1913	18.0	24.0	19.4	23.8	25.5	15.5	20.0	24.6		31.0	21.4	28.5	27.8		27.0	13.5
1915	22.3	28.5	22.0	27.3	28.3	16.0	23.5	28.0		35.8	23.0	31.5	31.3		31.3	16.0
1917	25.5	32.0	24.3	28.3	31.5	17.8	24.8	30.0		38.8	25.0	35.5	33.0		35.5	18.5
1921	31.5	38.8	30.0	32.5	37.5	19.8	29.5	36.5		47.0	30.3	39.5	39.8		40.5	24.3
1908		11.0	12.0		13.5	12.0	15.0	14.5	14.0	17.5	17.0	15.5	13.5		13.5	13.5
1913		23.0	23.1		24.1	21.0	21.9	25.8	21.3	29.8	29.0	23.0	21.5		25.1	22.4
1915		28.3	26.8		29.0	23.5	24.0	29.5	24.5	34.0	31.8	24.8	23.3		30.5	25.0
1917		31.8	29.5		32.0	24.0	25.0	32.3	26.5	37.0	35.0	26.0	25.0		34.5	28.0
1921		37.5	35.0		38.3	30.0	28.8	38.0	31.3	42.0	39.8	31.0	27.8		39.5	34.3
1908			12.5	9.0	17.0	13.0	13.0	14.0	12.5	9.5	17.5	16.0	12.0	6.0	11.0	9.0
1913			22.3	17.8	28.0	23.6	23.5	23.8	21.0	17.3	30.5	26.5	19.5	8.9	24.1	18.6
1915			25.8	20.5	30.3	25.3	26.5	26.5	23.0	19.5	34.8	29.0	21.8	10.0	28.0	22.3
1917			28.0	23.5	31.0	27.0	28.5	29.0	24.5	21.0	37.3	31.8	23.8	10.8	31.0	26.0
1921			33.0	28.0		30.8	31.3	35.5	27.5	27.5	43.0	38.0	27.3		37.0	32.5
1908		13.0		13.5	14.0	13.0	13.0	14.5	15.0	16.0	12.0	17.0	14.5			12.0
1913		25.0		25.0	21.0	19.0	24.5	22.9	27.1	27.6	28.9	28.5	25.0			24.0
1915		29.8		29.5	23.0	20.5	28.8	25.8	32.0	30.5	32.3	32.5	29.0			28.5
1917		31.5		33.0	25.0	22.0	30.5	28.8	35.0	32.0	34.5	35.5	31.0			32.0
1921		37.3		39.8	29.3	24.8	36.5	34.0	41.3	38.0	39.5	41.8	36.0			38.8
1908		13.5	14.0		16.0	15.5	14.5		12.0	15.5	14.0	13.5	14.0	15.0	13.0	
1913		26.0	26.3		24.8	25.8	28.6		22.9	27.5	24.5	24.0	24.1	26.5	26.0	
1915		30.0	30.0		26.3	28.8	32.3		26.3	30.8	27.5	26.3	27.5	30.8	31.0	
1917		33.5	33.5		28.0	31.0	31.5		28.5	33.5	30.0	29.5	29.5	33.5	34.0	
1921		38.5	39.0		33.8	36.5	41.3		35.3	38.5	35.0	34.5	34.8	39.8	39.3	
1908	12.5	12.5	17.0	15.0	10.0	14.0	10.5	16.0	16.0	11.0	15.5	15.0	17.5			
1913	25.5	25.0	30.5	29.0	21.0	24.6	21.0	28.0	28.9	22.5	24.4	27.1	29.8			
1915	30.5	28.5	34.3	33.5	23.5	27.3	24.8	32.3	32.0	25.5	27.0	31.0	33.5			
1917	33.5	28.5	37.0	36.5	25.3	30.0	27.0	36.0	35.0	27.0	29.3	34.5	36.0			
1921	39.3	33.0	42.0	41.5	30.3	35.5	31.3	40.5	41.0	31.5	34.0	38.8	40.8			
1908	10.5	13.0	16.5	14.0	13.5	14.5	13.5	14.0	14.0	16.0	14.0	15.5	17.5	13.0	8.0	
1913	22.8	26.3	30.9	25.0	24.8	24.1	26.0	25.1	23.3	27.0	26.3	26.8	29.5	26.5	19.0	
1915	29.5	31.0	36.0	28.8	28.8	27.0	30.5	28.8	26.5	30.3	29.5	30.5	32.8	31.3	22.8	
1917	30.5	34.8	39.0	31.0	32.0	29.5	33.0	32.0	28.0	31.5	32.0	33.0	35.0	34.0	26.3	
1921	37.0	39.8	44.5	37.0	37.3	35.5	38.0	37.5	32.8	38.0	37.5	39.0	39.8	40.0	32.5	

TABLE III. — *Graves Orchard: Trunk Circumferences of Individual Trees (Inches)* — Concluded.

	PLOT 1.		PLOT 2.		PLOT 3.		PLOT 4.		PLOT 5.		PLOT 6.		PLOT 7.		PLOT 8.	
Row.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1908	8.5	12.0	14.0	11.5	16.5	11.5	10.0	14.0	15.0	17.5	13.0	15.0	14.5			
1913	21.3	20.8	25.5	23.5	29.8	20.0	21.0	26.5	25.9	29.0	23.0	27.3	27.6			
1915	25.5	23.3	29.5	27.0	33.8	22.8	24.8	30.0	30.0	33.0	25.5	30.8	31.0			
1917	28.0	25.0	31.5	30.0	36.0	23.5	27.8	32.5	33.0	35.3	27.5	34.0	34.5			
1921	31.0	29.5	35.8	36.8	41.3	30.5	32.0	36.0	39.0	40.5	31.8	38.5	39.0			
1908	7.5	12.0	14.0		15.5	12.0	13.0	16.0	15.0	11.0	12.5	14.0	14.0			
1913	19.0	21.8	26.5		25.5	19.0	21.0	24.5	23.5	16.5	20.4	21.8	24.0			
1915	19.5	24.3	29.8		28.8	20.8	23.8	28.8	26.5	17.8	23.0	24.0	25.8			
1917	22.0	26.0	32.5		30.8	23.0	25.5	31.3	28.8	18.5	25.0	26.0	28.5			
1921	28.5	32.0	38.0		37.8	26.5	29.0	35.8	33.5	23.5	30.0	31.5	35.5			
1908			11.0	15.0	15.0	14.0	14.0		14.5	11.0	10.0	15.5	16.0			
1913			16.8	25.5	21.6	20.5	22.9		21.0	20.4	17.0	21.5	24.0			
1915			18.0	27.8	23.3	23.3	25.0		22.5	22.5	20.0	23.0	26.3			
1917			19.5	29.3	24.3	29.0	28.0		24.3	26.0	22.0	23.0	28.0			
1921			25.0	33.3	32.0	32.0	32.0		28.0	31.5	28.3	31.3	35.8			
1908		8.5	10.0	14.0	13.5	14.0	16.0	9.0	11.0	11.5		13.0	11.0			
1913		15.0	19.4	22.5	21.0	19.0	24.6	14.8	17.9	15.6		19.5	16.9			
1915		17.3	22.5	25.0	22.3	20.5	26.0	16.5	19.5	19.8		22.3	20.3			
1917		20.5	25.5	27.0	25.0	21.5	27.8	19.5	21.5	18.0		25.0	22.5			
1921		28.5	32.5	32.5	31.3	28.0	31.5	25.8	27.5			32.0	29.8			
1908	5.0				12.0	15.0	12.5	13.5	12.0							
1913	12.3				18.5	21.6	18.8	22.1	15.0							
1915	15.5				20.3	22.3	19.8	25.5	18.3							
1917	19.3				22.0	24.5	22.0	28.0	20.8							
1921	27.8				29.3	28.3	27.0	35.8	28.8							
1908		11.0	13.5	15.0	14.5											
1913		23.3	23.9	24.0	20.0											
1915		26.3	26.8	27.5	19.5											
1917		30.3	29.5	30.5	20.5											
1921		36.8	38.5	39.0	25.8											
1908	9.0															
1913	17.8															
1915	21.5															
1917	26.0															
1921	32.5															

TABLE IV. — *Graves Orchard: Yield of Baldwin Trees (Pounds).*

Plot.	Row.	Number of Trees.	1911.	1912.	1914.	1915.	1916.	1917.
1	1	9			1,215	1,114	3,040	1,056
	2	13			1,357	3,817	4,191	2,433
	Total	22	2,023	326				
2	1	16			4,000	3,866	5,780	2,736
	2	14			2,331	2,773	3,719	1,269
	Total	30	6,519	1,307				
3	1	17			2,380	3,993	2,294	4,549
	2	16			964	2,199	1,069	2,806
	Total	33	7,734	2,216				
4	1	16			801	6,154	3,230	4,569
	2	14			1,175	5,560	3,154	3,484
	Total	30	6,540	1,125				
5	1	14			3,410	2,237	4,796	1,121
	2	14			5,944	3,706	4,922	2,827
	Total	28	3,179	1,642				
6	1	13			6,073	1,974	4,886	2,294
	2	15			5,648	3,475	4,413	3,059
	Total	28	7,040	1,625				
7	1	15			5,697	4,076	3,183	1,624
	2	5			1,070	1,125	827	1,561
	Total	20	5,581	907				
8	1	6			3,213	1,230	3,868	1,114
	2	7			1,130	1,052	1,164	1,766
	Total	13	2,124	146				

TECHNICAL BULLETIN No. 5.

DEPARTMENT OF VETERINARY SCIENCE.

CONCERNING THE DIAGNOSIS OF BACTERIUM PULLORUM INFECTION IN THE DOMESTIC FOWL.

BY GEORGE EDWARD GAGE.

During the years 1916, 1917, 1919 and 1920 special studies have been conducted in this department concerning the diagnosis of *Bact. pullorum* infection in chicks and adult birds. The object in view has been to determine factors which aid in accuracy of diagnosis. Therefore the plan here is to set forth the data obtained which may be of some value in substantiating the work of others, and to add any data from experimental studies and routine which may assist those who have to do with the pullorum problem.

Among the points to be considered by the laboratory and field worker in the *Bact. pullorum* problem, the following are of interest: —

1. Are there a *Bacterium pullorum* A and a *Bacterium pullorum* B?
2. Can infections with *Bacterium pullorum* and *Bacterium sanguinarium* be differentiated?
3. Is *Bacterium sanguinarium* (fowl typhoid) widely distributed in Massachusetts?
4. Is it necessary to submit suspicious *Bacterium pullorum* cultures to biochemical tests before a diagnosis is justified?
5. Is either *Bacterium pullorum* or *Bacterium sanguinarium* related to the so-called "paralysis" so widely distributed at certain periods of the year in Massachnsetts?
6. Is *Bacterium sanguinarium* of any significance as the cause of epidemic disease in very young chicks?
7. What is the present status of the specificity of the agglutination test as a means of control of *Bacterium pullorum* infection in young chicks?

Historical.

The presence of cholera-like or typhoid-like epidemics in domestic birds dates back many years, but careful study extends only from the last quarter of a century. For a most excellent historical résumé of these studies from 1789 to 1913, the reader is referred to Hadley (1).

Since 1913 several investigators have added much to our knowledge concerning the biology of *Bact. pullorum.* Smith and Ten Broeck (2),

carrying out five sets of experiments in which serum of rabbits immunized with heated cultures of human typhoid, fowl typhoid and *Bact. pullorum*, considered that the agglutination tests were sufficiently definite to enable them to group the fowl typhoid and pullorum types together, both demonstrating the same intimate relation to typhoid bacilli. Again, in another paper (3), these writers demonstrated that fowl typhoid has many diagnostic features in common with the human typhoid bacillus, namely, the behavior toward carbohydrates and the agglutination reactions.

Rettger and Koser (4) carried out agglutination tests using reacting sera from rabbits immunized by subcutaneous injections, first of killed suspensions and later of living suspensions of *Bact. pullorum* and *Bact. sanguinarium*. Five days after the injections of heated vaccine, the rabbits were bled and the agglutinative power of the sera tested against definite suspensions of both *Bact. pullorum* and *Bact. sanguinarium*. No difference in agglutination properties was manifested. Attempts were made to increase the agglutination titre by the injection of living organisms. The titre remained the same and no change in the agglutinative ability of the two sera was manifested. Although these organisms have several characters in common, and particularly the serological reactions, they constitute two separate and distinct types, each bearing a specific relationship to the disease with which it has been associated, namely, either bacillary white diarrhœa or fowl typhoid. Taylor (5) concludes from his studies on fowl typhoid that the lesions produced in fowls which are infected with *Bact. sanguinarium* resemble in many respects those produced by *Bact. pullorum*, but, although there is a still closer resemblance in the biological characters of the two organisms, there is enough difference to warrant the conclusion that they are distinctly different diseases. Ward and Gallagher (6), studying forty-seven birds for comparison of agglutination and intradermal tests on naturally infected birds, report the absolute failure of each test as judged by the other test and by an autopsy, findings being similar in amount. Field tests on two hundred and thirty-one birds made simultaneously with the agglutination test at thirty-eight hours failed to detect one case reported positive to the other test.

Pfeiler and Rehse (7) present the clearest description of an epidemic in fowls due to the fowl typhoid bacillus. The fermentative reaction showed the organism to be similar to the human typhoid bacillus. According to Goldberg (8) the principal differences between the strains of *Bact. pullorum* and *Bact. sanguinarium* studied lie in the fact that *Bact. pullorum* produces gas in various carbohydrates while *Bact. sanguinarium* lacks this power in any of the carbohydrates he used, which included sugar-free media containing dextrose, lactose, saccharose, mannite, dextrine, inuline, galactose, levulose, raffinose, amygdalin, arabinose, adonite, dulcite, xylose, salicin, isodulcite, mannose, starch, glycerine, erythrol. The difference in gas production, as well as in their actions on milk, maltose, dulcite, dextrine, and isodulcite seems to indicate that these two organisms are distinct species of bacteria.

Hadley (1) concludes from his studies on the colon-typhoid intermediates that in carbohydrate media used known types of *Bact. pullorum*, *B. gallinarum*, *B. avisepticus*, *B. paratyphosus* A and B, manifest definite fermentative differences which justify regarding them as distinct species. Since paratyphoid A does not ferment xylose, a close relationship is shown between the types from poultry (pullorum and gallinarum) and paratyphoid B. The data presented indicate that pullorum is much less active than gallinarum on xylose. Aside from gas production there is a closer fermentative relation between *B. gallinarum* and the paratyphoids than between *Bact. pullorum* and the paratyphoids; this is due to the fact that pullorum is maltose-dextrine-dulcite negative. Hadley also finds that all the maltose-dextrine-dulcite negative strains isolated from chicks have been aerogenic, while all of the maltose-dextrine-dulcite negative strains isolated from adult birds were anaerogenic. The author has been able to isolate from the eggs of fowls experiencing infections with the maltose-dextrine-dulcite negative anaerogenic strains both aerogenic and anaerogenic forms. The gas production may vary quantitatively within wide limits. The writer has found that no one of the many original aerogenic pullorum strains, cultivated for years in artificial media, has lost its aerogenic power when placed under favorable conditions for growth; and none (either pullorum or gallinarum) that originally lacked this power ever attained it. According to these data one may conclude that if a strain, possessing otherwise the characteristics of pullorum or of gallinarum, is aerogenic it is not *B. gallinarum*, while if it is anaerogenic it may be either *Bact. pullorum* B or *B. gallinarum*. This indicates that it is necessary to make use of the maltose-dextrine-dulcite fermentation tests only when the strain in question is anaerogenic. In another paper (9) this same author concludes from his data that gas production by *Bact. pullorum* may depend upon whether the cultures are grown in glucose extract or glucose infusion broth. Propagating cultures for many years on artificial media does not cause them to lose their gas-producing ability. *Bact. pullorum* isolated from epidemics of bacillary white diarrhœa in young chicks or from infected eggs is aerogenic; there exist also anaerogenic strains which, in all the cases in which they have been observed, have been isolated from adult fowls experiencing acute or subacute infections simulating fowl typhoid in both clinical symptoms and pathological alterations of tissues. Therefore the writer proposes tentatively to postulate for *Bact. pullorum:* (1) *Bact. pullorum* A, aerogenic; and *Bact. pullorum* B, anaerogenic, pathogenic for adult stock only.

Hadley (10) suggests that *Bact. pullorum* appears to stand as a borderline group in the colon-typhoid intermediates, separating the actual paratyphoids from the actual paracolons; and further suggests that, in order to facilitate bringing about some degree of order in the group of colon-typhoid intermediates, gas-forming strains be referred to the paracolon group which should be revived; and that anaerogenic forms only be referred to the paratyphoid group, in which *B. gallinarum* (Klein) might stand as the type species.

Rettger and Koser (4) present data which indicate that dextrine, maltose and dulcite are attacked by *Bact. sanguinarium* with the production of acid but no gas. *Bact. pullorum* produces, on the other hand, no visible change of media containing these agents except slight alkali production. *Bact. pullorum* acts upon dextrose and mannite with evolution of appreciable amounts of gas, while *Bact. sanguinarium*, whether recently isolated or artificially cultivated for many years, does not produce gas in any of the carbohydrate media. Prolonged cultivation of *Bact. pullorum* in the laboratory does not cause this organism to lose its power of producing gas in dextrose and mannite broth. These authors conclude that *Bact. pullorum* manifests itself only as the cause of natural epidemic infection in young chicks. They further maintain that *Bact. sanguinarium* attacks fowls of different ages, and is of relatively little, if indeed any, significance as the cause of epidemic disease in very young chicks.

Mulsow (11) concludes from his studies that *B. avisepticus* may generally be distinguished from *Bact. sanguinarium* by its action in milk, indol production, fermentation of carbohydrates, agglutination reaction and pathogenesis. *Bact. pullorum* and *Bact. sanguinarium* do not produce indol, generally form hydrogen sulphid in lead acetate medium, and produce a temporary acidity in milk, but later alkalinity. As regards fermentation, *Bact. pullorum* produces acid and generally gas in the same carbohydrates, and in addition produces acid in dulcite and maltose. According to this author, *Bact. pullorum* may be distinguished from *Bact. sanguinarium* by the inability of the former to ferment dulcite, while the latter ferments this carbohydrate. *Bact. sanguinarium* generally produces acid promptly in maltose, and does not produce gas in any of the carbohydrates. Rhamnose is fermented promptly by *Bact. pullorum*, while *Bact. sanguinarium* produces acid only after forty-eight hours' incubation. It appears that there are sufficient differences, reported in this paper by Mulsow, between *Bact. sanguinarium* and *Bact. pullorum* to regard these as separate types.

Krumwiede and Kohn (12) report results which indicate that the essential characteristic of the paratyphoid-enteritidis group is the ability of its members to produce acid from rhamnose, differentiating both the aerogenic and anaerogenic members from *B. typhosus*. They point out that, without due regard to low and latent avidity for carbohydrates in relation to variability and practical differentiation, erroneous differential significance might easily be given to variation even among members of the fixed groups.

Experimental.

In the experiments presented, a study has been made of 112 different strains of *Bact. pullorum* isolated from diseased materials from poultry plants in various parts of Massachusetts, to determine, if possible, biochemical and cultural details which are constant enough to warrant their recommendation as a part of the procedure in diagnosis. The following organisms, listed in Table 1, have been isolated from cases of chick disease,

clinically white diarrhœa, and these conformed morphologically, biochemically and serologically to this group of organisms. It was further decided to study the uniformity of these 112 cultures biochemically and serologically, and to determine how many of them gave reactions which were similar to the reactions of its close relative, the fowl typhoid organism (*Bact. sanguinarium*). The cultures of *Bact. sanguinarium* were isolated from birds sent here for diagnosis, and the Smith, Cornell and Gage strains. There were five strains in this list. The two other than the three mentioned appeared typical of sanguinarium, were isolated during the early part of 1920, and designated the Humphrey and Massachusetts strains, respectively.

The following table lists the cultures of *Bact. pullorum* isolated and studied during the course of this work: —

TABLE 1. — *Strains of Bacterium Pullorum studied in this Investigation.*

Bacterium Pullorum.	Source of Culture.	When Isolated and Studied.
Strain No. 1 . . .	M. A. C. Amherst, Mass. Isolated March, 1914, from M. A. C. chick. Used in summer of 1914 as Strain A.	March, 1914
Strain No. 2 . . .	Experimental material from this laboratory. From unabsorbed yolk of chick inoculated summer of 1913 with S_3 (S_3 from Cutler egg). Used in summer of 1914 as Strain B.	
Strain No. 3 . . .	Isolated from material sent to laboratory. Used as Strain C in summer of 1914.	
Strain No. 4 . . .	Bridgewater, Mass. Isolated from Cutler chick. Used as S_2 in 1913. Used as Strain D in 1914.	
Strain No. 5 . . .	Maryland. Used at Maryland Experiment Station in 1911.	
Strain No. 6 . . .	Sterling, Mass. Isolated 1914. Trask Strain. Used as Strain F in summer of 1914.	May 1, 1914
Strain No. 7 . . .	Holliston, Mass. Isolated from chicks sent by C. E. Cristman, Silverwood Farm, Holliston, Mass. These chicks were bought of A. B. H. Arnold, Holliston, Mass.	Feb. 20, 1915
Strain No. 8 . . .	M. A. C. Amherst, Mass. No. 231 (2703) from unabsorbed yolk (chick).	Mar. 31, 1915
Strain No. 9 . . .	Holliston, Mass. Isolated from unabsorbed yolk of chick. Isolated from liver of chick.	
Strain No. 10 . . .	Northborough, Mass. Isolated from liver of chick .	Apr. 1, 1915
Strain No. 11 . . .	Franklin, Mass. 11-1 isolated from unabsorbed yolk of chick No. 2; 11-2 isolated from liver of chick No. 5.	
Strain No. 12 . . .	North Hadley, Mass. 12-1 from unabsorbed yolk of chick No. 1; 12-2 from unabsorbed yolk of chick No. 4; 12-3 from unabsorbed yolk of chick No. 9.	Apr. 5, 1915
Strain No. 13 . . .	Kingston, Mass. Isolated from unabsorbed yolk of chick No. 2.	Apr. 5, 1915
Strain No. 14 . . .	Center Marshfield, Mass. Isolated from unabsorbed yolk of chick No. 4.	Apr. 6, 1915
Strain No. 15 . . .	Brookline, Mass. Isolated from unabsorbed yolk of chick No. 1.	Apr. 7, 1915
Strain No. 16 . . .	Amherst, Mass. Isolated from liver of chick No. 1; 16-2 isolated from unabsorbed yolk of chick No. 1; 16-3 isolated from liver of chick No. 2.	Apr. 12, 1915
Strain No. 17 . . .	Southborough, Mass. 17-1 isolated from liver of chick No. 1; 17-2 isolated from heart of chick No. 2; 17-3 isolated from heart of chick No. 3; 17-4 isolated from unabsorbed yolk of chick No. 4; 17-5 isolated from unabsorbed yolk of chick No. 5; 17-6 isolated from unabsorbed yolk of chick No. 6.	Apr. 16, 1915
Strain No. 18 . . .	Littleton, Mass. 18-1 isolated from heart of chick No. 1; 18-2 isolated from liver of chick No. 1.	Apr. 17, 1915
Strain No. 19 . . .	Andover, Mass. Isolated from unabsorbed yolk of chick No. 1.	Apr. 22, 1915

Table 1. — *Strains of Bacterium Pullorum studied in this Investigation* — Continued.

Bacterium Pullorum.	Source of Culture.	When Isolated and Studied.
Strain No. 20 . . .	Westborough, Mass. Isolated from unabsorbed yolk of chick No. 2.	Apr. 23, 1915
Strain No. 21 . . .	Amherst, Mass. Chicks hatched from eggs bought at Hickory Farm, Ludlow, Mass. 21-1 isolated from heart of chick; 21-2 isolated from liver of chick.	May 15, 1915
Strain No. 22 . . .	Shrewsbury, Mass. Isolated from unabsorbed yolk of chick No. 1.	May 13, 1915
Strain No. 23 . . .	Natick, Mass. Isolated from liver of chick No. 1 .	May 14, 1915
Strain No. 24 . . .	Lowell, Mass. 24-1 isolated from unabsorbed yolk of chick No. 1; 24-2 isolated from unabsorbed yolk of chick No. 2.	May 15, 1915
Strain No. 25 . . .	South Hadley, Mass. 25-1 isolated from liver of chick No. 1; 25-2 isolated from unabsorbed yolk of chick No. 2.	June 2, 1915
Strain No. 26 . . .	Amherst, Mass. 26-1 isolated from liver of chick No. 1; 26-2 isolated from liver of chick No. 2.	June 2, 1915
Strain No. 27 . . .	Dedham, Mass. 27-1 isolated from liver of chick No. 1; 27-2 isolated from liver of chick No. 2.	June 2, 1915
Strain No. 28 . . .	Belchertown, Mass. Isolated from liver and unabsorbed yolk of chick.	May 2, 1916
Strain No. 29 . . .	Nobscot, Mass. 29-1 isolated from liver and unabsorbed yolk of chick; 29-2 isolated from liver and unabsorbed yolk of chick; 29-3 isolated from liver and unabsorbed yolk of chick; 29-4 isolated from liver and unabsorbed yolk of chick.	July 28, 1916
Strain No. 30 . . .	Concord, Mass. 30-1 isolated from liver and unabsorbed yolk of chick; 30-2 isolated from liver and unabsorbed yolk of chick; 30-3 isolated from liver and unabsorbed yolk of chick; 30-4 isolated from liver and unabsorbed yolk of chick; 30-5 isolated from liver and unabsorbed yolk of chick; 30-6 isolated from liver and unabsorbed yolk of chick.	Mar. 24, 1916
Strain No. 31 . . .	Holliston, Mass. 31-1 isolated from unabsorbed yolk of chick; 31-2 isolated from liver of chick; 31-3 isolated from unabsorbed yolk of chick.	May 2, 1917
Strain No. 32 . . .	Shrewsbury, Mass. Isolated from unabsorbed yolk of chick.	Feb. 28, 1917
Strain No. 33 . . .	Morrisville, N. Y. 33-1 isolated from unabsorbed yolk of chick; 33-2 isolated from unabsorbed yolk of chick.	Mar. 28, 1917
Strain No. 34 . . .	Egypt, Mass. Isolated from unabsorbed yolk of chick.	Mar. 16, 1917
Strain No. 35 . . .	Plainville, Mass. Isolated from unabsorbed yolk of chick.	Apr. 15, 1917
Strain No. 36 . . .	Fitchburg, Mass. 36-1 isolated from liver of chick; 36-2 isolated from liver of chick.	Apr. 13, 1917
Strain No. 37 . . .	Lunenburg, Mass. Isolated from liver of chick; 37-2 isolated from liver of chick.	Apr. 13, 1917
Strain No. 38 . . .	Sutton, Mass. 38-1 isolated from unabsorbed yolk of chick; 38-2 isolated from liver of chick.	Apr. 13, 1917
Strain No. 39 . . .	Southborough, Mass. Isolated from liver of chick	Apr. 16, 1917
Strain No. 40 . . .	Cohasset, Mass. Isolated from unabsorbed yolk of chick.	Apr. 16, 1917
Strain No. 41 . . .	Amherst, Mass. 41-1 isolated from unabsorbed yolk of chick; 41-2 isolated from unabsorbed yolk of chick; 41-3 isolated from unabsorbed yolk of chick; 41-4 isolated from unabsorbed yolk of chick.	Apr. 15, 1917
Strain No. 42 . . .	Shirley, Mass. 42-1 isolated from unabsorbed yolk of chick; 48-2 isolated from unabsorbed yolk of chick.	Apr. 18, 1917
Strain No. 43 . . .	Middleton, Mass. 43-1 isolated from ovary of chick; 43-2 isolated from ovary of chick.	Apr. 21, 1917
Strain No. 44 . . .	Spencer, Mass. Isolated from liver of chick . .	May 2, 1917
Strain No. 45 . . .	Greenfield, Mass. 45-1 isolated from liver of chick; 45-2 isolated from liver of chick.	May 3, 1917
Strain No. 46 . . .	Winchendon, Mass. 46-1 isolated from liver of chick; 46-2 isolated from liver of chick.	May 8, 1917

TABLE 1. — *Strains of Bacterium Pullorum studied in this Investigation* — Continued.

Bacterium Pullorum.	Source of Culture.	When Isolated and Studied.
Strain No. 47 . . .	Pittsfield, Mass. Isolated from liver of chick . .	May 7, 1917
Strain No. 48 . . .	Peabody, Mass. 48-1 isolated from unabsorbed yolk of chick; 48-2 isolated from unabsorbed yolk of chick.	May 24, 1917
Strain No. 49 . . .	Weymouth, Mass. 49-1 isolated from unabsorbed yolk of chick; 49-2 isolated from unabsorbed yolk of chick; 49-3 isolated from unabsorbed yolk of chick; 49-4 isolated from unabsorbed yolk of chick.	Apr. 10, 1917
Strain No. 50 . . .	Westfield, Mass. Isolated from unabsorbed yolk of chick.	May 21, 1917
Strain No. 51 . . .	Methuen, Mass. Isolated from liver of chick . .	Mar. 7, 1920
Strain No. 52 . . .	Methuen, Mass. Isolated from unabsorbed yolk of chick.	Mar. 7, 1920
Strain No. 53 . . .	Methuen, Mass. Isolated from unabsorbed yolk of chick.	Mar. 7, 1920
Strain No. 54 . . .	Methuen, Mass. Isolated from heart of chick . .	Mar. 7, 1920
Strain No. 55 . . .	Webster, Mass. Isolated from unabsorbed yolk of chick.	Mar. 15, 1920
Strain No. 56 . . .	Webster, Mass. Isolated from heart of chick . .	Mar. 15, 1920
Strain No. 57 . . .	Webster, Mass. Isolated from unabsorbed yolk of chick.	Mar. 15, 1920
Strain No. 58 . . .	Andover, Mass. Isolated from unabsorbed yolk of chick.	Mar. 19, 1920
Strain No. 59 . . .	Andover, Mass. Isolated from liver of chick . .	Mar. 19, 1920
Strain No. 60 . . .	Natick, Mass. Isolated from unabsorbed yolk of chick.	Mar. 19, 1920
Strain No. 61 . . .	Natick, Mass. Isolated from unabsorbed yolk of chick.	Mar. 19, 1920
Strain No. 62 . . .	Natick, Mass. Isolated from heart of chick . .	Mar. 19, 1920
Strain No. 63 . . .	Natick, Mass. Isolated from unabsorbed yolk of chick.	Mar. 19, 1920
Strain No. 64 . . .	Hubbardston, Mass. Isolated from liver of chick .	Mar. 23, 1920
Strain No. 65 . . .	Hubbardston, Mass. Isolated from liver of chick .	Mar. 23, 1920
Strain No. 66 . . .	Hubbardston, Mass. Isolated from unabsorbed yolk of chick.	Mar. 23, 1920
Strain No. 67 . . .	Hubbardston, Mass. Isolated from liver of chick .	Mar. 23, 1920
Strain No. 68 . . .	Lexington, Mass. Isolated from heart of chick .	Apr. 8, 1920
Strain No. 69 . . .	Lexington, Mass. Isolated from liver of chick .	Apr. 8, 1920
Strain No. 70 . . .	Lexington, Mass. Isolated from liver of chick .	Apr. 8, 1920
Strain No. 71 . . .	Lexington, Mass. Isolated from heart of chick .	Apr. 8, 1920
Strain No. 72 . . .	Longmeadow, Mass. Isolated from liver of chick .	Apr. 3, 1920
Strain No. 73 . . .	Plymouth, Mass. Isolated from liver of chick .	Apr. 3, 1920
Strain No. 74 . . .	Essex, Mass. Isolated from heart of chick . .	Apr. 9, 1920
Strain No. 75 . . .	Worcester, Mass. Isolated from unabsorbed yolk of chick.	Apr. 9, 1920
Strain No. 76 . . .	Worcester, Mass. Isolated from unabsorbed yolk of chick.	Apr. 9, 1920
Strain No. 77 . . .	Belchertown, Mass. Isolated from unabsorbed yolk of chick.	Apr. 9, 1920
Strain No. 78 . . .	Bridgewater, Mass. Isolated from liver of chick .	Apr. 12, 1920
Strain No. 79 . . .	Bridgewater, Mass. Isolated from unabsorbed yolk of chick.	Apr. 12, 1920
Strain No. 80 . . .	Wellesley, Mass. Isolated from unabsorbed yolk of chick.	Apr. 14, 1920
Strain No. 81 . . .	East Braintree, Mass. Isolated from liver of chick	Apr. 14, 1920

TABLE 1.—*Strains of Bacterium Pullorum studied in this Investigation*—Concluded.

BACTERIUM PULLORUM.	Source of Culture.	When Isolated and Studied.
Strain No. 82 . . .	M. A. C. Amherst, Mass. Isolated from liver of chick.	Apr. 20, 1920
Strain No. 83 . . .	M. A. C. Amherst, Mass. Isolated from unabsorbed yolk of chick.	Apr. 20, 1920
Strain No. 84 . . .	M. A. C. Amherst, Mass. Isolated from unabsorbed yolk of chick.	Apr. 20, 1920
Strain No. 85 . . .	Chester, Mass. Isolated from unabsorbed yolk of chick.	Apr. 21, 1920
Strain No. 86 . . .	Chester, Mass. Isolated from liver of chick . .	Apr. 21, 1920
Strain No. 87 . . .	Chester, Mass. Isolated from liver of chick . .	Apr. 21, 1920
Strain No. 88 . . .	Boston, Mass. Isolated from liver of chick . .	Apr. 21, 1920
Strain No. 89 . . .	Leominster, Mass. Isolated from liver of chick .	Apr. 21, 1920
Strain No. 90 . . .	Medway, Mass. Isolated from liver of chick . .	Apr. 27, 1920
Strain No. 91 . . .	Medway, Mass. Isolated from liver of chick . .	Apr. 27, 1920
Strain No. 92 . . .	Wakefield, Mass. Isolated from liver of chick . .	Apr. 27, 1920
Strain No. 93 . . .	Wakefield, Mass. Isolated from liver of chick .	Apr. 27, 1920
Strain No. 94 . . .	M. A. C. Amherst, Mass. Isolated from unabsorbed yolk of chick.	Apr. 27, 1920
Strain No. 95 . . .	M. A. C. Amherst, Mass. Isolated from liver of chick.	Apr. 27, 1920
Strain No. 96 . . .	Littleton, Mass. Isolated from heart of chick . .	Apr. 30, 1920
Strain No. 97 . . .	Bedford, Mass. Isolated from liver of chick . .	Apr. 30, 1920
Strain No. 98 . . .	Bedford, Mass. Isolated from liver of chick . .	Apr. 30, 1920
Strain No. 99 . . .	Worcester, Mass. Isolated from liver of chick . .	May 4, 1920
Strain No. 100 . . .	Worcester, Mass. Isolated from liver of chick . .	May 4, 1920
Strain No. 101 . . .	West Acton, Mass. Isolated from liver of chick .	May 7, 1920
Strain No. 102 . . .	West Acton, Mass. Isolated from liver of chick .	May 7, 1920
Strain No. 103 . . .	Woonsocket, R. I. Isolated from liver of chick .	May 11, 1920
Strain No. 104 . . .	Woonsocket, R. I. Isolated from liver of chick .	May 11, 1920
Strain No. 105 . . .	Woonsocket, R. I. Isolated from liver of chick .	May 11, 1920
Strain No. 106 . . .	Belchertown, Mass. Isolated from unabsorbed yolk of chick.	May 14, 1920
Strain No. 107 . . .	Segreganset, Mass. Isolated from liver of chick .	May 18, 1920
Strain No. 108 . . .	Waltham, Mass. Isolated from liver of chick . .	May 21, 1920
Strain No. 109 . . .	Charlemont, Mass. Isolated from unabsorbed yolk of chick.	May 28, 1920
Strain No. 110 . . .	Hampton Falls, N. H. Isolated from liver of chick	May 29, 1920
Strain No. 111 . . .	Southwick, Mass. Isolated from liver of chick .	May 19, 1920
Strain No. 112 . . .	Hudson, Mass. Isolated from unabsorbed yolk of chick.	June 3, 1920

Change of Reaction in Carbohydrate Media by the 112 Strains of Bacterium Pullorum.

The cultures of *Bact. pullorum* were grown in test tubes of uniform length and caliber and in standard beef extract bouillon containing 1 per cent of the carbohydrate. These results were somewhat lower than those obtained by Goldberg (8), who found by using infusion broth that the percentage was higher. According to Hadley (10), on an average 0.7 per cent more acid is produced in sugar-infusion broth than in sugar-extract broth. Two drops of a bouillon suspension of each strain were used as the inoculum for a test, triplicate titrations made, and the average percentage acidity noted at the end of the fifth day. It appeared from our work in relation to time of acid production that the maximum occurred between the fifth and tenth day. Therefore the tables and curves represent the amount of acid at the end of a five-day period, at 37.5° C., expressed in percentage normal acid. All titrations were made in the cold, using $\frac{N}{20}$ NaOH and $\frac{N}{20}$ HCl and phenolphthalein as the indicator. Gas production was determined in dextrose, galactose, mannite, levulose, arabinose, salicin, mannose, xylose, adonite, erythrol, saccharose, dulcite, dextrine, lactose, raffinose, inulin, maltose and glycerine. Durham double-barreled fermentation tubes were employed, and the percentage of gas in the inner tube read off on the Frost gasometer chart at the end of five days' incubation at 37.5° C.

Dextrose. — This sugar was fermented by all the 112 strains. The lowest amount of acidity was 0.6 per cent and the highest 1.8 per cent, the mean of 108 determinations being 1.4 per cent acid. Gas was produced in this carbohydrate by all strains, ranging in quantity from a bubble to 55 per cent, the average for all the 112 strains being 20 per cent.

Mannite. — The acid production in mannite was greater than in dextrose and much more variable. After five days' growth the 112 strains had produced an average of 1.0 per cent acidity. The exceptions to this average were strains 23, 46 and 72 which produced 2.0 per cent, 2.2 per cent, and 1.7 per cent, respectively. Gas was produced by all strains, ranging in quantity from 20 to 50 per cent, with an average for the 112 strains of 30 per cent.

Galactose. — This sugar was fermented by all strains, being very much like mannite and dextrose. The acidity ranged from 0.1 to 2.1 per cent, the average for all cultures being 0.9 per cent. There were four exceptions which make a wide variation in the curve, — strains 29, 33, 42 and 49, which produced 0.1, 1.9, 2.0 and 2.1 per cent, respectively.

Levulose. — This sugar was fermented easily by all strains of *Bact. pullorum*, and the changes in reaction here correspond with those in dextrose, mannite and galactose, the acidity ranging from 0.2 to 2.0 per cent, the average for the 112 strains being 0.9 per cent. The exceptions were strains 63, 72 and 73, which produced 2.0, 1.9 and 1.5 per cent acidity, respectively.

Arabinose. — All strains fermented this carbohydrate, the acidity ranging from 0.5 to 1.0 per cent, with an average for the 112 strains of 0.7 per cent. This carbohydrate was fermented in a very variable manner.

Salicin. — None of the 112 strains fermented salicin. On the fifth day there was marked alkaline reaction in some strains. The average acidity for the 112 strains was 0.1 per cent.

Mannose. — This sugar was fermented by all the strains. The minimum acidity by any strain was 0.6 and the maximum 1.3 per cent. The average for the 112 strains was 0.9 per cent acid.

Xylose. — This sugar was fermented by all the strains, but none produced marked quantities of acid. The minimum produced by any strain was 0.1 and the maximum 0.4 per cent, with a mean of 0.25 per cent for the 112 strains. Therefore it may be said that these pullorum strains are not strongly xylose positive.

Adonite. — For the most part the initial acidity was not greatly changed. The minimum figure observed was an alkalinity of 0.1 per cent and the maximum an acidity of 0.1 per cent. As a group these strains were adonite-negative, the curve of results from the 112 strains running close to the line of initial acidity.

Erythrol. — This carbohydrate was not fermented significantly by any of the cultures of *Bact. pullorum* studied. All strains gave a reduction of the initial acidity. The acidity ranged from a minimum of —0.4 per cent to a figure which represented no change from original acidity. Therefore these 112 strains are erythrol negative.

Saccharose. — There was no appreciable amount of acid produced in this carbohydrate. The minimum reading was —0.2 per cent and a few readings showed no change from the initial acidity. The average acidity determination for the 112 strains was —0.2 per cent. There were two exceptions, strains 67 and 84, which showed a determination of —0.4 and —0.5 per cent for acidity. Therefore in saccharose there is no acid formed by *Bact. pullorum*.

Dulcite. — All the 112 strains of *Bact. pullorum* showed a marked reduction of acidity. A few strains did not change the initial acidity, the range being between no change of acidity and —0.4 per cent. There were three exceptions, however, cultures 32, 46 and 47, which produced the following results: —0.6, —0.5 and —0.5 per cent, respectively. Therefore it may be said that the results from these determinations indicate that *Bact. pullorum* is dulcite negative.

Dextrine. — The initial acidity was readily reduced by all strains studied. The readings ranged from no change in acidity to —0.3 per cent. There were no exceptions, all cultures demonstrating this reduction.

Lactose. — The initial acidity was reduced by all strains. The readings ranged from no change in acidity to —0.4 per cent, the mean reading being —0.12 per cent. *Bact. pullorum* may be considered, consequently, lactose-negative as regards acid production. Two strains, 93 and 109, were unusually prompt in this particular. Both strains gave a reading of —0.4.

Raffinose. — The acidity was reduced by all the pullorum strains. The average reading for the 112 cultures was —0.2 per cent. Strain 48 was capable of greater alkaline production than the others, giving a result of —0.5 per cent.

Inulin. — All strains of *Bact. pullorum* were negative in this carbohydrate, the mean reading being —0.19 per cent. There was a prompt reduction in initial acidity, only one culture of the 112 showing no change in the initial acidity.

Maltose. — None of the 112 strains produced any acid. The change was usually marked in all tubes on the fifth day. There was an average reduction of acidity of —0.18 per cent.

Glycerine. — None of the 112 strains produced any acid in glycerine. The determination on the fifth day showed a reduction in the final acidity, averaging —0.1 per cent.

Conclusions from the Fermentation Tests.

From the tests reported concerning the fermentation of the 112 strains of *Bact. pullorum*, it appears that this organism is positive in dextrose, galactose, mannose, mannite, levulose, xylose and arabinose; and negative in glycerine, maltose, adonite, dulcite, lactose, dextrine, saccharose, inulin, erythrol and raffinose. In salicin there is a slight indication of fermentation, at least a slight acidity in a large percentage of the strains. All strains of this organism studied showed a marked tendency to produce gas in

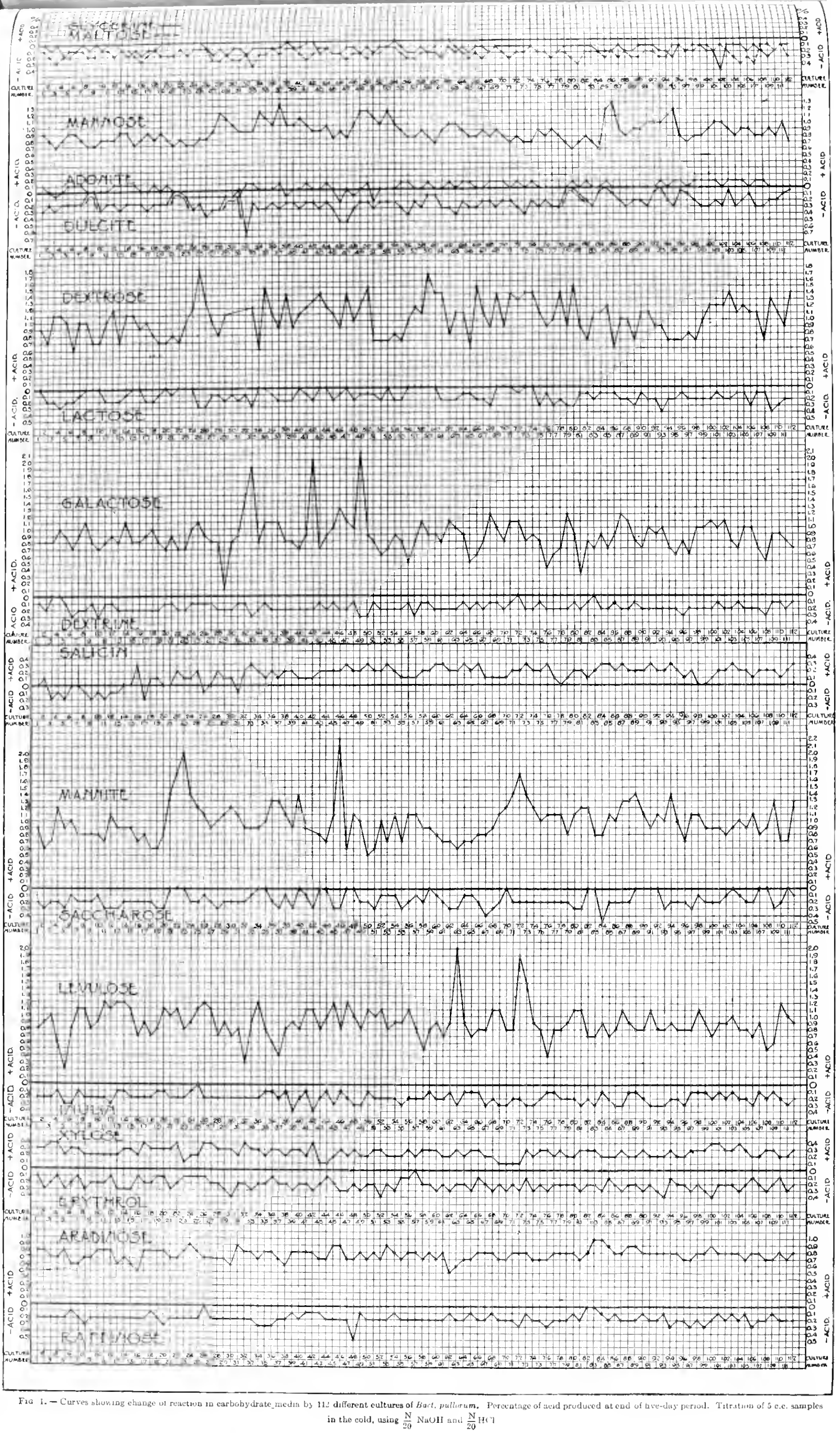


FIG. 1. — Curves showing change of reaction in carbohydrate media by 112 different cultures of *Bact. pullorum*. Percentage of acid produced at end of five-day period. Titration of 5 c.c. samples in the cold, using $\frac{N}{20}$ NaOH and $\frac{N}{20}$ HCl

Ma
by an
strain
Xyl
quanti
0.4 pe
said tl
Ado
minim
acidity
of resu
Ery
cultur
The ac
no cha
Sac
hydra
chang
strain
showe
saccha
Dul
acidity
no ch
cultur
—0.5
detern
Dex
readin
ceptio
Lac
from
cent.
acid p
Both
Raf
readin
alkalin
Inu
mean
acidity
Ma
marke
—0.18
Gly
detern
—0.1

Fro
of *Ba*
galac
in gly
eryth
tion,
of th

dextrose. This aerogenic property of the pullorum strains is persistent. Cultures of pullorum carried for fourteen months in France during the war, and kept under adverse conditions, when planted again under favorable conditions regained their aerogenic properties, and the activities in this direction were as marked as in the original cultures. The 112 strains of *Bact. pullorum* studied, even after being transferred eighteen times, still retain active gas production in dextrose and mannite. In one exception, culture No. 44, there has never developed more than a bubble of gas in the dextrose. This is recorded in the table in the dextrose column as B, meaning bubble. All strains are methyl red negative. Therefore from previous morphological and cultural tests, linked with these biochemical findings, it may be concluded that the organism classed to-day as *Bact. pullorum* A should be a slender, non-motile, non-liquefying, gram-negative bacillus. It does not coagulate or peptonize milk. It produces gas in dextrose and mannite, forms H_2S in lead acetate medium, does not produce indol, and does not reduce nitrates.

Fermentation Tests with Bacterium Sanguinarium.

Dextrose. — This sugar was fermented by all the five strains, 0.8 per cent being the highest amount and 0.7 per cent the lowest, the mean being 0.7 per cent.

Mannite. — All cultures of *Bact. sanguinarium* produced about the same quantity of acidity, 0.8 per cent.

Galactose. — Fermented by *Bact. sanguinarium*, the percentage acidity being 0.7, 0.7, 0.6, 0.8 and 0.7 per cent, respectively.

Levulose. — Fermented more variably than galactose, 0.6 per cent being the lowest figure, and 0.9 per cent the highest.

Arabinose. — All strains fermented this carbohydrate, the readings being between 0.6 and 0.8 per cent acid.

Salicin. — Not fermented by the five strains.

Mannose. — This carbohydrate was fermented by *Bact. sanguinarium* about the same as mannite.

Xylose. — Fermented less actively in this carbohydrate, the readings being 0.5, 0.3, 0.2, 0.5 and 0.4 per cent acidity, respectively.

Adonite. — Not appreciably fermented by *Bact. sanguinarium.* The maximum figure obtained was 0.1 per cent acidity.

Erythrol. — Not fermented significantly by any of the five strains of *Bac. sanguinarium.*

Saccharose. — Not fermented by *Bact. sanguinarium.* There was increased alkalinity.

Dulcite. — In this carbohydrate the initial acidity was increased, 0.4 per cent being the maximum amount determined in any of the five cultures.

Dextrine. — There was a marked increase in acidity, four of the five strains of *Bact. sanguinarium* showing 0.6 per cent.

Lactose. — There was no increase in acidity by *Bact. sanguinarium.* There was a marked production of alkalinity.

Raffinose. — There was no increase in acidity in this carbohydrate; the initial acidity was markedly reduced.

Inulin. — There was no increase in acidity in this carbohydrate; the initial acidity was markedly reduced.

Maltose. — Large increase in acid was noted by all strains of *Bact. sanguinarium* in this carbohydrate.

Glycerine. — None of the strains of *Bact. sanguinarium* produced any acid in glycerine. The determination on the fifth day showed a reduction in initial acidity.

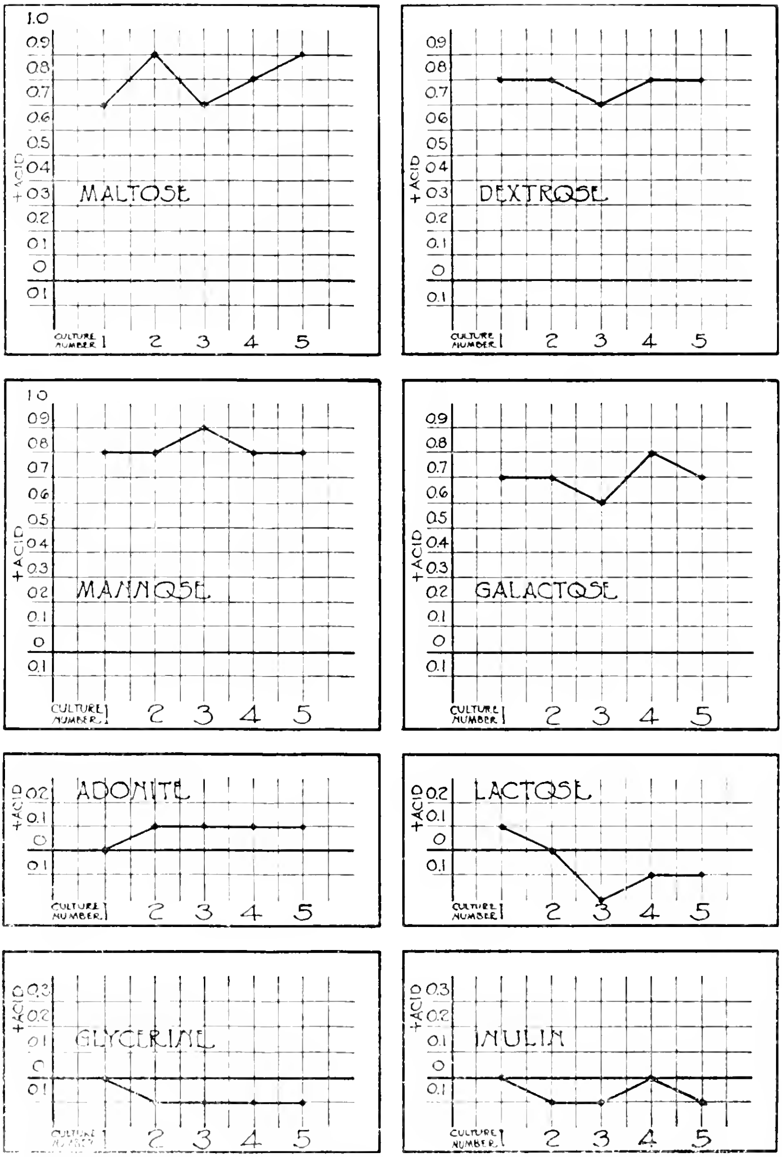


FIG. 2. — Curves showing change of reaction in carbohydrate media by cultures of *Bacterium sanguinarium*. Percentage of acid produced at end of five-day period. Titration of 5 c.c. samples in the cold, using $\frac{N}{20}$ NaOH and $\frac{N}{20}$ HCl.

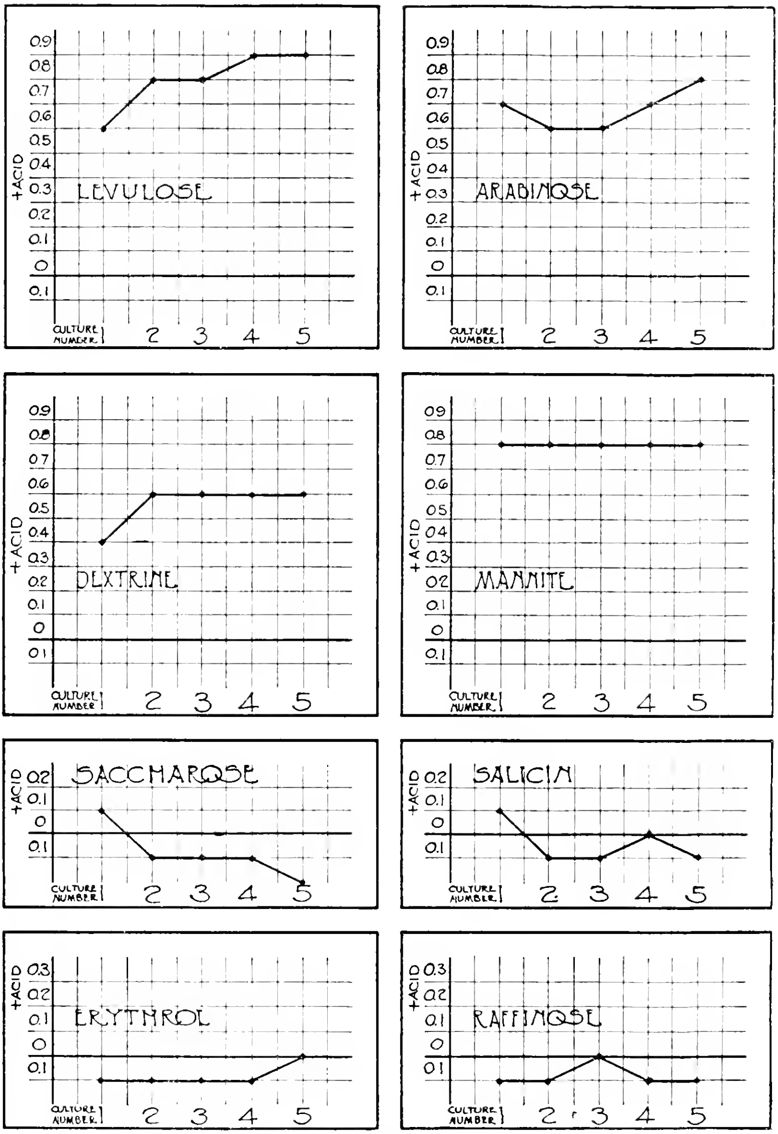


FIG. 2. — Curves showing change of reaction in carbohydrate media by cultures of *Bacterium sanguinarium* — *Continued.*

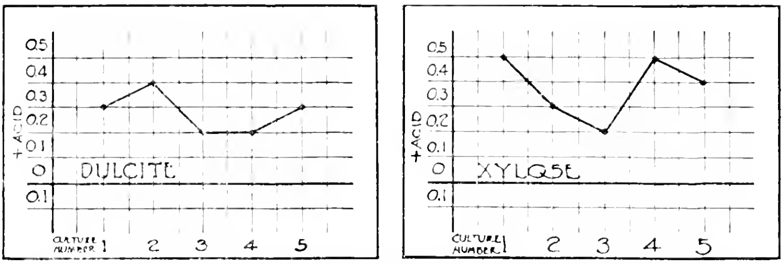


FIG. 2. — Curves showing change of reaction in carbohydrate media by cultures of *Bacterium sanguinarium* — *Concluded*.

TABLE 2. — *Gas Production of the 112 Strains of Bacterium pullorum in Carbohydrate Broth.*

[Percentage of gas in closed arm of fermentation tube.]

Culture Number.	Dextrose.	Mannite.	Galactose.	Levulose.	Arabinose.	Salicin.	Mannose.	Xylose.	Dulcite.	Culture Number.	Dextrose.	Mannite.	Galactose.	Levulose.	Arabinose.	Salicin.	Mannose.	Xylose.	Dulcite.
1 .	17	20	0	0	0	0	26	0	0	57 .	20	45	0	0	0	0	25	0	0
2 .	33	50	0	0	0	0	30	0	0	58 .	15	30	0	0	0	0	30	0	0
3 .	37	35	0	B	4	43	30	5	25	59 .	18	25	0	0	0	0	20	0	0
4 .	43	30	0	0	0	25	0	0	0	60 .	17	40	0	0	0	0	20	0	0
5 .	25	25	0	B	0	0	20	0	0	61 .	10	25	0	0	0	0	25	0	0
6 .	30	30	5	0	0	0	20	0	0	62 .	25	45	5	B	0	0	30	0	0
7 .	55	25	0	0	0	0	30	0	0	63 .	18	45	0	0	0	0	22	0	0
8 .	12	20	0	0	0	0	20	0	0	64 .	22	40	0	0	0	0	20	0	0
9 .	15	30	0	0	0	0	30	0	0	65 .	10	35	0	0	0	0	25	0	0
10 .	10	25	0	0	0	0	20	0	0	66 .	12	30	0	0	0	0	30	0	0
11 .	16	30	0	0	0	0	B	0	0	67 .	19	25	0	0	0	0	30	0	0
12 .	16	25	0	0	0	0	B	0	0	68 .	22	25	0	0	0	0	B	0	0
13 .	10	25	0	B	0	0	B	0	0	69 .	23	45	0	0	0	0	20	0	0
14 .	22	25	0	0	0	0	B	0	0	70 .	16	35	0	0	0	0	25	0	0
15 .	10	25	0	0	0	0	25	0	0	71 .	22	30	0	0	0	0	20	0	0
16 .	17	30	0	0	0	0	0	0	0	72 .	17	30	0	0	0	0	30	0	0
17 .	13	30	0	0	0	0	12	0	0	73 .	17	30	0	0	0	0	20	0	0
18 .	14	30	0	0	0	0	15	0	0	74 .	20	20	0	0	0	0	20	0	0
19 .	20	30	0	0	0	0	25	0	0	75 .	17	30	0	0	0	0	20	0	0
20 .	10	25	0	0	0	0	25	0	0	76 .	28	30	0	0	0	0	25	0	0
21 .	20	40	0	0	0	0	22	0	0	77 .	17	30	0	0	0	0	26	0	0
22 .	13	30	0	0	0	0	18	0	0	78 .	18	30	0	0	0	0	20	0	0
23 .	13	30	0	0	0	0	25	0	0	79 .	20	25	0	0	0	0	25	0	0

B—Bubble. 0—No gas.

Adonite, erythrol, saccharose, dextrine, lactose, raffinose, inulin, maltose and glycerine produced no gas with any of the cultures.

TABLE 2. — *Gas Production of the 112 Strains of Bacterium Pullorum in Carbohydrate Broth* — Concluded.

Culture Number.	Dextrose.	Mannite.	Galactose.	Levulose.	Arabinose.	Salicin.	Mannose.	Xylose.	Dulcite.	Culture Number.	Dextrose.	Mannite.	Galactose.	Levulose.	Arabinose.	Salicin.	Mannose.	Xylose.	Dulcite.
24 .	17	20	0	0	0	0	5	0	0	80 .	27	40	0	0	0	0	20	0	0
25 .	15	30	10	0	0	0	35	0	0	81 .	20	30	0	0	0	0	25	0	0
26 .	28	30	0	0	0	0	B	0	0	82 .	13	30	0	0	0	0	20	0	0
27 .	23	30	0	0	0	0	25	0	0	83 .	15	25	0	0	0	0	20	0	0
28 .	18	25	0	0	0	0	15	0	0	84 .	27	25	0	0	0	0	25	0	0
29 .	20	45	0	0	0	0	B	0	0	85 .	20	25	0	0	0	0	20	0	0
30 .	10	20	0	0	0	0	B	0	0	86 .	13	25	0	0	0	0	20	0	0
31 .	20	45	0	0	0	0	32	0	0	87 .	15	30	0	0	0	0	25	0	0
32 .	13	40	0	0	0	0	35	0	0	88 .	25	25	0	0	0	0	20	0	0
33 .	30	35	0	0	0	0	15	0	0	89 .	22	30	0	0	0	0	20	0	0
34 .	27	30	0	0	0	0	35	0	0	90 .	20	20	0	0	0	0	25	0	0
35 .	25	25	0	B	0	0	25	0	0	91 .	23	20	0	0	0	0	30	0	0
36 .	27	30	0	0	0	0	25	0	0	92 .	47	45	5	B	0	0	20	0	0
37 .	25	45	0	0	0	0	35	0	0	93 .	10	35	0	0	0	0	25	0	0
38 .	28	35	0	0	0	0	35	0	0	94 .	10	30	0	0	0	0	20	0	0
39 .	25	40	0	0	0	0	0	0	0	95 .	20	25	0	0	0	0	30	0	0
40 .	25	30	0	0	0	0	30	0	0	96 .	25	30	0	0	0	0	0	0	0
41 .	29	35	0	0	0	0	18	0	0	97 .	10	25	0	0	0	0	0	0	0
42 .	45	45	10	10	0	0	5	0	0	98 .	23	20	0	0	0	0	20	0	0
43 .	8	30	0	0	0	0	15	0	0	99 .	27	50	0	0	0	0	25	0	0
44 .	B	20	0	0	0	0	28	0	0	100 .	17	35	0	0	0	0	15	0	0
45 .	20	30	0	0	0	0	22	0	0	101 .	13	30	0	0	0	0	10	0	0
46 .	48	25	15	0	0	0	35	0	0	102 .	17	25	0	0	0	0	25	0	0
47 .	5	25	0	0	0	0	0	0	0	103 .	40	30	10	B	0	0	30	0	0
48 .	27	30	0	0	0	0	0	0	0	104 .	33	25	0	0	0	0	20	0	0
49 .	10	0	0	0	0	0	0	0	0	105 .	30	20	5	B	0	0	20	0	0
50 .	20	50	0	0	0	0	30	0	0	106 .	28	30	0	0	0	0	25	0	0
51 .	17	30	0	0	0	0	B	0	0	107 .	25	25	0	0	0	0	25	0	0
52 .	30	25	0	0	0	0	B	0	0	108 .	17	30	0	0	0	0	30	0	0
53 .	12	25	0	0	0	0	25	0	0	109 .	20	25	0	0	0	0	20	0	0
54 .	32	30	10	0	0	0	B	0	0	110 .	28	20	0	0	0	0	20	0	0
55 .	17	20	0	0	0	0	40	0	0	111 .	10	25	0	0	0	0	25	0	0
56 .	22	30	0	0	0	0	25	0	0	112 .	22	25	0	0	0	0	25	0	0

B=Bubble. 0=No gas.

Adonite, erythrol, saccharose, dextrine, lactose, raffinose, inulin, maltose and glycerine produced no gas with any of the cultures.

TABLE 3.—*Summary of Biochemical Data as Regards Fermentation of the 112 Strains of Bacterium Pullorum.*

[Acid[1] and gas[2] production.]

Culture	Dextrose		Mannite		Galactose		Levulose		Arabinose		Salicin		Mannose		Xylose		Adonite		Erythrol		Saccharose		Dulcite		Dextrine		Lactose		Raffinose		Inulin		Maltose		Glycerine	
	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas	Acid	Gas
1	+	+	+	+	+	—	+	—	+	—	O	—	—	+	+	—	+	—	—	—	—	—	—	—	—	—	O	—	—	—	—	—	—	—	O	—
2	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	+	+	+	+	+	—	+	B	+	+	—	+	—	+	+	+	—	—	—	—	—	—	—	+	O	—	—	—	—	—	—	—	—	—	O	—
4	+	+	+	+	+	—	+	—	+	—	—	+	—	—	+	—	O	—	—	—	—	—	—	—	O	—	—	—	—	—	—	—	—	—	—	—
5	+	+	+	+	+	—	+	B	+	—	—	—	—	+	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	+	+	+	+	+	+	+	—	+	—	O	—	—	+	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7	+	+	+	+	+	—	+	—	+	—	O	—	—	+	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	O	—
8	+	+	+	+	+	—	+	—	+	—	—	—	—	+	+	—	O	—	—	—	—	—	O	—	—	—	O	—	—	—	—	—	—	—	—	—
9	+	+	+	+	+	—	+	—	+	—	—	—	—	+	+	—	O	—	—	—	—	—	O	—	—	—	O	—	—	—	—	—	—	—	O	—
10	+	+	+	+	+	—	+	—	+	—	—	—	—	+	+	—	O	—	—	—	—	—	—	—	—	—	O	—	—	—	—	—	—	—	—	—
11	+	+	+	+	+	—	+	—	+	—	—	—	—	B	+	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	O	—
12	+	+	+	+	+	—	+	—	+	—	—	—	—	B	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	O	—
13	+	+	+	+	+	—	+	B	+	—	—	—	—	B	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
14	+	+	+	+	+	—	+	—	+	—	O	—	—	B	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
15	+	+	+	+	+	—	+	—	+	—	O	—	—	+	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16	+	+	+	+	+	—	+	—	+	—	+	—	—	—	+	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17	+	+	+	+	+	—	+	—	+	—	—	—	—	+	+	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	O	—
20	+	+	+	+	+	—	+	—	+	—	O	—	—	+	+	—	+	—	—	—	—	—	—	—	—	—	O	—	—	—	—	—	—	—	O	—
21	+	+	+	+	+	—	+	—	+	—	O	—	—	+	+	—	O	—	—	—	O	—	O	—	—	—	—	—	—	—	—	—	—	—	O	—
22	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	O	—	—	—	O	—	O	—	—	—	O	—	—	—	—	—	—	—	O	—
23	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	—	—	—	—	O	—	—	—	—	—	O	—	—	—	—	—	—	—	O	—
24	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	—	—	—	—	—	—	—	—	—	—	O	—	—	—	—	—	—	—	O	—
25	+	+	+	+	+	+	+	—	+	—	+	—	—	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	O	—	—	—	O	—
26	+	+	+	+	+	—	+	—	+	—	—	—	—	B	+	—	—	—	—	—	—	—	—	—	—	—	—	—	O	—	—	—	—	—	—	—
27	+	+	+	+	+	—	+	—	+	—	O	—	—	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
28	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
29	+	+	+	+	+	—	+	—	+	—	+	—	—	B	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30	+	+	+	+	+	—	+	—	+	—	+	—	—	B	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
31	+	+	+	+	+	—	+	—	+	—	—	—	—	+	+	—	—	—	—	—	—	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—
32	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
33	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
34	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	O	—	—	—	O	—	—	—	—	—	O	—	—	—	—	—	—	—	—	—
35	+	+	+	+	+	—	+	B	+	—	+	—	—	+	+	—	O	—	—	—	O	—	—	—	—	—	O	—	—	—	—	—	—	—	—	—
36	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
37	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
38	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	O	—
39	+	+	+	+	+	—	+	—	+	—	+	—	—	—	+	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
40	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	O	—	—	—	O	—	—	—	—	—	O	—	—	—	—	—	—	—	—	—
41	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	O	—
42	+	+	+	+	+	+	+	+	+	—	+	—	—	+	+	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	O	—
43	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	O	—	—	—	O	—	—	—	—	—	O	—	—	—	—	—	—	—	—	—
44	+	B	+	+	+	—	+	—	+	—	+	—	—	+	+	—	+	—	—	—	O	—	—	—	—	—	O	—	—	—	—	—	—	—	—	—
45	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
46	+	+	+	+	+	+	+	—	+	—	+	—	—	+	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
47	+	+	+	+	+	—	+	—	+	—	+	—	—	—	+	—	O	—	—	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
48	+	+	+	+	+		+	—	+		+	—	—	—	+	—	—	—	—	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
49	+	+	+	+	+	—	+	—	+	—	+	—	—	—	+	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
50	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
51	+	+	+	+	+	—	+	—	+	—	+	—	—	B	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
52	+	+	+	+	+	—	+	—	+	—	+	—	—	B	+	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
53	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	O	—	—	—	—	—	—	—	—	—	O	—	—	—	—	—	—	—	—	—
54	+	+	+	+	+	+	+	—	+	—	+	—	—	B	+	—	O	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	O	—
55	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
56	+	+	+	+	+	—	+	—	+	—	+	—	—	+	+	—	+	—	—	—	—	—	—	—	—	—	O	—	—	—	—	—	—	—	—	—

[1] + = acid production.
— = alkali production.
O = neutral.

[2] + = gas produced.
— = no gas produced.
B = bubble (not enough to measure).

TABLE 3. — *Summary of Biochemical Data as Regards Fermentation of the 112 Strains of Bacterium Pullorum* — Concluded.

[Acid[1] and gas[2] production.]

CULTURE	DEXTROSE		MANNITE		GALACTOSE		LEVULOSE		ARABINOSE		SALICIN		MANNOSE		XYLOSE		ADONITE		ERYTHROL		SACCHAROSE		DULCITE		DEXTRINE		LACTOSE		RAFFINOSE		INULIN		MALTOSE		GLYCERINE	
	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS	ACID	GAS
57	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	O	−	−	−	−	−	−	−	O	−	−	−	−	−	−	−	−	−
58	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	O	−	−	−	−	−	−	−	−	−
59	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	O	−	−	−	−	−	O	−	−	−	−	−	−	−	−	−
60	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	O	−	−	−	−	−	−	−	−	−
61	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	O	−	−	−
62	+	+	+	+	+	+	+	B	+	−	+	−	+	+	+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	O	−	−	−
63	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
64	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
65	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
66	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
67	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
68	+	+	+	+	+	−	+	−	+	−	+	−	+		+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
69	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	−	−	−	−	−	−	O	−	−	−	−	−	−	−	−	−
70	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	O	−	−	−	−	−	O	−	−	−	−	−	−	−	−	−
71	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	O	−	−	−	−	−	−	−	−	−
72	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	−	−	−	−	O	−	−	−	−	−	−	−	−	−	−	−
73	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	O	−	−	−	−	−	−	−	−	−
74	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	−	−	−	−	−	−	O	−	−	−	−	−	−	−	−	−
75	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
76	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
77	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
78	+	+	+	+	+	−	+	−	+	−	O	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
79	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−
80	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	−	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−
81	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
82	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	O	−	−	−	−	−	−	−	O	−	−	−	−	−	−	−
83	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	O	−	−	−	O	−	−	−	O	−	−	−	−	−	−	−
84	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
85	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	−	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−
86	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
87	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
88	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
89	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
90	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
91	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
92	+	+	+	+	+	+	+	B	+	−	+	−	+	+	+	−	O	−	−	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
93	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	−	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−
94	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
95	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
96	+	+	+	+	+	−	+	−	+	−	+	−	+	−	+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
97	+	+	+	+	+	−	+	−	+	−	+	−	+	−	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
98	+	+	+	+	+	−	+	−	+	−	O	−	+	+	+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
99	+	+	+	+	+	−	+	−	+	−	O	−	+	+	+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
100	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
101	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
102	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
103	+	+	+	+	+	+	+	B	+	−	+	−	+	+	+	−	+	−	−	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
104	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
105	+	+	+	+	+	+	+	B	+	−	+	−	+	+	+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
106	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
107	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
108	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	+	−	−	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
109	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
110	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
111	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
112	+	+	+	+	+	−	+	−	+	−	+	−	+	+	+	−	O	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−

1 + = acid production.
— = alkali production.
O = neutral.

2 + = gas produced.
— = no gas produced.
B = bubble (not enough to measure).

A comparison of the tables which have to do with *Bact. pullorum* with those which have to do with *Bact. sanguinarium* shows that *Bact. pullorum* is maltose-dextrine-dulcite negative, while *Bact. sanguinarium* is maltose-dextrine-dulcite positive. All freshly isolated strains of *Bact. pullorum* (139 strains) have produced gas, while the five strains of *Bact. sanguinarium* have never produced gas. The 112 strains of *Bact. pullorum* studied have been maltose-dextrine-dulcite negative. This agrees very well with the work of Hadley. Thus far we have isolated but one organism from chicks, showing typical symptoms of white diarrhœa, which did not produce gas in dextrose. This particular strain was maltose-dextrine-dulcite negative, and therefore would correspond to *Bact. pullorum* B or the anaerogenic pullorum form. During the current year, 1920–21, several anaerogenic forms have been isolated from adult hens, and they were maltose-dextrine-dulcite negative, which in a way helps to substantiate Hadley's claim that the *Bact. pullorum* infecting adult hens is maltose-dextrine-dulcite negative, but anaerogenic. The number of cases thus studied is meager, and future studies with more cases ought to give sufficient data to establish this point. Since Hadley has been able to isolate both aerogenic and anaerogenic forms of *Bact. pullorum* from the eggs of fowls experiencing infections with the maltose-dextrine-dulcite anaerogenic strains, and since the maltose-dextrine-dulcite negative strains isolated by him from chicks have been aerogenic, while all the maltose-dextrine-dulcite negative strains isolated from infections in adult birds have been anaerogenic, the duality of the *Bact. pullorum* type appears to be justified. The work presented in this paper substantiates Hadley's results. Besides, the gas production is of great value as a differential characteristic. Therefore it is essential in making a differential bacterial diagnosis for *Bact. pullorum* to note its special morphological characteristics; to ascertain its fermentation activities in maltose, dextrine and dulcite, and its aerogenicity. Doubtful cultures of *Bact. pullorum* should be submitted to the above biochemical tests before a differential diagnosis is justified. As a routine in this department, all doubtful cultures are tested for aerogenicity in dextrose, and for acidity in maltose; methyl red being used as an indicator for the increased acid production. The data at hand indicate that there are maltose-dextrine-dulcite negative strains which do not produce gas in dextrose, and these, whether found only in adult birds or not, should be classed as the *Bact. pullorum* B, different from the one so generally isolated from chicks, which is maltose-dextrine-dulcite negative, but produces gas in dextrose.

The fowl typhoid (*Bact. sanguinarium*) is characterized, aside from its specific morphology, as an anaerogenic non-motile bacillus. It does not form indol, nor reduce nitrates. It forms H_2S in lead acetate media. It is a maltose-dextrine-dulcite positive organism.

Distribution of Fowl Typhoid in Massachusetts.

During the seasons of 1919–20 and 1920–21, observations were made on all specimens sent to the laboratory for diagnosis, especially to note the presence of *Bact. sanguinarium*. During that time more than 600 different specimens were examined, and this anaerogenic, non-motile bacillus which was maltose-dextrine-dulcite positive was isolated but six times, — three times in the season of 1919–20 and three times in the season of 1920–21. These cases exhibited all the post-mortem findings peculiar to this disease. Especially noticeable were the enlarged spleen and the marked leukemic condition. There were, however, several maltose-dextrine-dulcite negative forms isolated which were anaerogenic, these classifying as *Bact. pullorum* B. During this same period 289 chicks, sent here with a history of bacillary white diarrhœa, were examined, and the true *Bact. pullorum* was isolated from all but one. This one strain was anaerogenic, and persistently gave a faint acid reaction in maltose when methyl red was used as an indicator. From this it would appear that in this one chick we were dealing with an organism which came close to the *Bact. sanguinarium* type. From these findings the writer is led to believe that the fowl typhoid infection in Massachusetts is infrequent, and that the *Bact. pullorum* B type is far from common. In our work of the last few years we have never isolated from eggs a *Bact. pullorum* form which was anaerogenic. All cultures have been aerogenic and have produced little or no acid in maltose, dextrine or dulcite.

Although this represents but two years' observations, there appears to be sufficient evidence to indicate that fowl typhoid is not widely distributed in Massachusetts; that it is not transmitted by the egg; and that *Bact. pullorum* of the B type is found frequently in adult stock.

Does either Bact. Pullorum or Bact. Sanguinarium play Any Part in the so-called "Paralysis" so widely distributed in Massachusetts?

During the course of the studies concerning the diagnosis of *Bact. pullorum*, there were brought to the laboratory many birds suffering with the so-called "paralysis," which even now is assuming a vast economic importance in the poultry industry in Massachusetts. The weakness of the legs and the listlessness of these birds were not essentially different from conditions produced in rabbits when inoculated with pure cultures of *Bact. pullorum*. With this in mind, all specimens exhibiting the paralytic symptoms were examined bacteriologically, with special reference to *Bact. pullorum* and *Bact. sanguinarium*. There were 83 paralytic specimens examined, and from 5 of them only was isolated *Bact. pullorum* of the aerogenic type. None of the 83 specimens exhibited the marked enlarged spleen and leukemic conditions found in fowl typhoid, as known to us in this laboratory. The anaerogenic maltose-dextrine-dulcite positive organism of fowl typhoid was not isolated from any of the 83 specimens. Cultural examinations were made of liver tissue, spleen, intestinal mucosa,

ovarian tissues, and lumbar region of the spinal cord. In this so-called "paralysis" all birds during life showed a rather bright red comb, the paleness being evident only a short time before death. There was never found at autopsy a marked leukemia. In fowl typhoid this leukemic condition is highly prominent, and for this reason Moore has called this paratyphoid type of infection "infectious leukemia." Hadley has observed a similar epidemic in fowls showing pronounced leukemic symptoms associated with *Bact. pullorum*. The writer has never observed this condition in relation to *Bact. pullorum* infections in adult birds.

From these observations on the 83 paralytic birds, with only 5 showing the presence of the *Bact. pullorum* infection, — these five probably having carried the infection since chickhood, — the evidence does not indicate that the paralytic disease so widely distributed at certain periods of the year in Massachusetts is due to the presence of either the pullorum or sanguinarium type.

Influence of Infection upon the Hatching Quality of Eggs and upon the Viability of Young Stock.

In 1917 and 1918 several sets of experiments were carried out under the best known conditions for poultry husbandry. Eggs from 60 hens known to have reacted positively to the agglutination test were set in an electrobator. When tested at the end of the first seven days of incubation, 30 were found to be infertile and 2 were found dead in the shell. Of the 28 left, 10 were hatched; 3 chicks died at the end of the first day and *Bact. pullorum* (aerogenic type) was isolated from the unabsorbed yolk. All eggs containing fully developed chicks were examined especially for *Bact. pullorum*, with the following results. The egg number in each case represents the number of the hen laying the egg.

TABLE 4. — *Results of Tests for Bacterium Pullorum in Dead Chicks from Eggs laid by Positively Reacting Birds.*

Egg Number.	Bact. pullorum.	Egg Number.	Bact. pullorum.
8001	+	7925	—
8381	+	7998	—
8388	—	8430	+
8002	—	8430	—
8002	—	8565	+
8430	+	8388	+
7925	—	7998	+
8565	—	8430	—
8001	+	8381	—

+=present. —=not present.

From this table it will be seen that with the methods used it was not possible to detect *Bact. pullorum* in all the dead chicks, although adult hens were all positively reacting to the agglutination test. From 8, *Bact. pullorum* was isolated without difficulty; from the other 10, the cultures were negative.

After three months, following out three sets of incubation, the author was able to obtain from the three sets of eggs set, 60 in each lot, all from positively reacting hens, 7 livable chicks on the first set, 9 on the second set, and 9 on the third set, and these chicks were all given the numbers of the parent stock from which they came: 7811, 7895, 7925, 7997, 7998, 8001, 8002, 8020, 8082, 8084, 8094, 8139, 8171, 8180, 8202, 8204, 8294, 8384, 8388, 8389, 8430, 8431, 8544, 8565, 8810. These 25 birds, all reared from positively agglutinating hens, were yarded together and blood taken at various times to determine whether their blood would show any signs of agglutinative powers.

When the chicks had grown to a weight of at least 400 grams, they were put together in the yard on Aug. 10, 1917. The following table shows the weight of each bird at that time: —

TABLE 5. — *Weight of Chicks on Aug. 10, 1917.*

CHICK NUMBER.	Weight (Grams).	CHICK NUMBER.	Weight (Grams.)
7811	870	8180	680
7895	1,200	8204	450
7925	1,240	8202	580
7997	860	8294	780
7998	1,249	8384	620
8001	1,160	8388	530
8002	1,130	8389	540
8020	680	8430	540
8082	950	8431	380
8084	1,490	8544	510
8094	730	8565	530
8139	1,050	8810	670
8171	780		

Agglutination tests were run on these birds, the first being on July 17, 1917. The following table shows the reactions for this and subsequent tests: —

Table 6. — *Records of Agglutination Tests on Chicks hatched from Eggs laid by Positively Reacting Hens.*[1]

Chick Number.	July 17 and 18, 1917. Dilution of Serum.					July 21, 1917. Dilution of Serum.					Aug. 3, 1917. Dilution of Serum.					Aug. 26, 1917. Dilution of Serum.					Nov. 7, 1917. Dilution of Serum.				
	1–100.	1–200.	1–500.	1–1000.	1–2000.	1–100.	1–200.	1–500.	1–1000.	1–2000.	1–100.	1–200.	1–500.	1–1000.	1–2000.	1–100.	1–200.	1–500.	1–1000.	1–2000.	1–100.	1–200.	1–500.	1–1000.	1–2000.
7811	?	?	?	?	?	C	?	?	?	?	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
7895	?	?	?	?	?	0	0	0	0	0	C	C	C	0	0	?	?	?	?	?					
7925	0	0	0	0	0	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
7997	C	C	0	0	0	0	0	0	0	0	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
7998	0	0	0	0	0	0	0	0	0	0	C	C	0	0	0	?	?	?	?	?	?	?	?	?	?
8001	0	0	0	0	0	?	?	?	?	?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8002	0	0	0	0	0	C	0	0	0	0	C	C	0	0	0	?	?	?	?	?	0	0	0	0	0
8020	0	0	0	0	0	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
8082	C	?	?	?	?	0	0	0	0	0	C	C	0	0	0	C	C	0	0	0					
8084	?	?	?	?	?	0	0	0	0	0	C	C	C	C	C	C	C	C	C	C	C	C	0	0	0
8094	0	0	0	0	0	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
8139	?	?	?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8171	?	?	?	?	?	?	?	?	?	?	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
8180	C	C	C	C	C	C	C	C	C	C	C	0	0	0	0	C	C	C	0	0	C	C	C	C	C
8202	0	0	0	0	0	0	0	0	0	0						C	C	C	C	C	C	C	C	C	C
8204	?	?	?	0	0	C	C	C	C	?	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
8294						0	0	0	0	0	C	C	C	C	C	C	C	0	0	0	C	C	C	C	C
8384	C	C	C	C	C	0	0	0	0	0	C	0	0	0	0	C	C	C	0	0	C	C	C	C	C
8388	?	?	?	?	?	C	C	C	C	C	?	?	?	?	?	C	C	0	0	0	C	C	0	0	0
8430	?	?	?	0	0	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
8565	?	?	?	?	?	C	C	C	C	C	C	C	C	C	0	C	C	C	C	C	C	C	C	C	C
8810	?	0	0	0	0	0	0	0	0	0	0	0	0	0	0	?	?	?	?	?					

[1] The symbols indicating various degrees of agglutination have been taken from Hadley, Journal of Immunology, Vol. 2, p. 463, 1917, as follows: C=complete agglutination; ?=doubtful agglutination; 0=no agglutination.

These experiments indicate that in chicks hatched from eggs laid by positively reacting hens, at least six months' time should elapse before the normal agglutination power of such sera would be sufficiently definite to furnish indication of past or present infection. The birds reared from hens 8001, 8139 and 8810 never showed any agglutinative power to their blood sera. The length of time a serum maintains its agglutination power has not as yet been determined.

The Present Status of the Specificity of the Agglutination Test as a Means of Control of Bacterium Pullorum Infection in Young Chicks.

During the last few years the agglutination test has become a popular means of recognition in the domestic fowl of those individuals which have contracted *Bact. pullorum* infections in chickhood; and consequently, as adult productive fowls, may have become, through infections in their ovaries, carriers of infection to the offspring. Several writers have demonstrated that there are certain factors which have influenced the test and which suggest the need of modification of the method in the direction of securing a higher degree of specificity. Hadley suggests that we stand in need of a means of diagnosis which shall distinguish between a latent (presumably ovarian) and a past infection. The data presented up to date indicate that not all adult hens with *Bact. pullorum* have infections localized in the ovaries; and also that not all infection has its origin in an attack of bacillary white diarrhœa experienced in the chick stage. This point, as Hadley suggests, is of less significance in its bearing upon the validity of the results of agglutination tests for *Bact. pullorum* infection than is the question of the specificity of the test. This author as well as others has demonstrated the interagglutinability of *Bact. pullorum*, fowl typhoid and other antigens in both *Bact. pullorum* and fowl typhoid serum. Fowls which have been experimentally immunized against different types of fowl typhoid possess serum which agglutinates *Bact. pullorum* antigens quite as well as it agglutinates its homologous antigen. According to these data the agglutination test for the recognition of *Bact. pullorum* infection appears to lose some of its claim to specificity; and to this extent, without carefully going over the results as obtained in field and laboratory co-operating, it may be open to criticism.

If all operations both in field and laboratory are considered, however, the reader will be convinced that the test yields valuable results. From our work, already reported, during the seasons of 1919–20 and 1920–21, there were only six cases where the anaerogenic type of organism was isolated and the post-mortem examinations revealed the enlarged spleen associated with leukemic conditions. This indicates that, at least so far as this laboratory has been called upon to make examinations, fowl typhoid infections are infrequent. That all infections are localized in the ovary is yet to be proven. It can be said, however, that the ovarian infections are not rare, and when they are present they persist. During the course of the examination of hundreds of eggs for *Bact. pullorum* infection, only the true aerogenic form of *Bact. pullorum* was isolated. Strains of these cultures, even after four years, maintained this aerogenic property and were maltose-dextrine-dulcite negative. Therefore these studies indicate that fowl typhoid is not transmitted to the egg. In all of our work in the bacteriological examination of young chicks, in all cases showing large unabsorbed yolks, we have been able to isolate only the aerogenic type of organism, and this in hundreds of cases. This shows an apparent lack of

susceptibility of young stock to the *Bact. sanguinarium* type of infection, and appears to substantiate the work of Dr. Hadley, who states that he has examined large numbers of cultures derived from young stock, but has not encountered among them the *Bact. sanguinarium* type.

In this laboratory hundreds of agglutination tests have been made to demonstrate the interagglutinability of *Bact. pullorum* with *Bact. sanguinarium*, *B. typhosus*, *B. paratyphosus* A, and *B. paratyphosus* B. The results obtained here agree with those from other laboratories: *i.e.*, that the agglutinative tests are sufficiently definite for grouping the fowl typhoid and pullorum types together, both demonstrating the same intimate relation to typhoid bacilli. In every test made, the *Bact. pullorum* immune serum agglutinates typhoid antigen better than typhoid serum agglutinates pullorum antigen. *Bact. sanguinarium* immune serum agglutinates *Bact. pullorum* much better than it does typhoid. There has never been demonstrated any indication of an affinity of interagglutinability between *B. avisepticus* (fowl cholera) and the pullorum and sanguinarium types. While it is true that by our present methods it is difficult to differentiate sanguinarium and pullorum by agglutination, this does not mean that application of the test will not yield valuable results. Already, from the work of three years, the typical maltose-dextrine-dulcite positive anaerogenic fowl typhoid organism has been isolated six times, and in this study more than 600 specimens were examined. This indicates that fowl typhoid is not widespread, at least in Massachusetts.

From the preceding biochemical data the establishment of *Bact. pullorum* and *Bact. sanguinarium* as separate types is justifiable. Therefore if it can be proven that breeding birds showing a positive agglutination reaction may lay eggs, from which are hatched chicks developing white diarrhœa symptoms, and at death the internal organs yield cultures which demonstrate morphologically an organism which is slender, non-motile, gram-negative, gelatine non-liquefying, and is aerogenic, demonstrating no acidity in maltose, dextrine and dulcite, the agglutination test would not be invalid as an economic measure in the identification of this infection. With this in mind, an experiment was carried out to this end.

Twenty breeding flocks were selected, all showing positively reacting birds, and the following spring all the dead chicks from these places were examined bacteriologically, with special reference to identifying the small gram-negative, maltose-dextrine-dulcite negative organism which was aerogenic. The following table shows the details of the tests: —

TABLE 7. — *Results on Identification of Cultures isolated from Dead Chicks which had been hatched from Eggs laid by Positively Reacting Breeding Birds.*

[Materials for study obtained from 20 different parts of Massachusetts.]

Flock Number.	Breeding Birds.		Cultures isolated from Dead Chicks.	(Fermentation) Acid in —			Gas Production (Aerogenicity) in Dextrose.	Agglutinability by Pullorum Serum.	Identification.
	Number in Flock.	Number with Positive Agglutination Test.		Maltose.	Dextrine.	Dulcite.			
1	51	16	2 Y 3 H 3 Y	— — —	— — —	— — —	+ + +	+C (1-400) +C (1-400) +C (1-400)	*Bact. pullorum* A
2	219	26	1 L 2 Y 3 Y 4 H	— — — —	— — — —	— — — —	+ + + +	+C (1-400) +C (1-400) +C (1-400) +C (1-400)	*Bact. pullorum* A
3	216	45	29 Y	—	—	—	+	+C (1-400)	*Bact. pullorum* A
4	51	20	22 L	—	—	—	+	+C (1-400)	*Bact. pullorum* A
5	36	3	24 Y 25 Y	— —	— —	— —	+ +	+C (1-400) +C (1-400)	*Bact. pullorum* A
6	1,194	244	29 Y	—	—	—	+	+C (1-400)	*Bact. pullorum* A
7	784	14	31 Y 32 Y 33 Y	— — —	— — —	— — —	+ + +	+C (1-200) +C (1-200) +C (1-200)	*Bact. pullorum* A
8	250	51	39 L 40 L	— —	— —	— —	+ +	+C (1-200) +C (1-200)	*Bact. pullorum* A
9	89	13	45 H	—	—	—	+	+C (1-200)	*Bact. pullorum* A
10	393	29	52 L 53 L 54 L	— — —	— — —	— — —	+ + +	+C (1-200) +C (1-200) +C (1-200)	*Bact. pullorum* A
11	138	21	60 L	—	—	—	+	+C (1-200)	*Bact. pullorum* A
12	76	6	61 Y	—	—	—	+	+C (1-200)	*Bact. pullorum* A
13	882	129	1 L 2 Y 3 Y 4 H	— — — —	— — — —	— — — —	+ + + +	+C (1-200) +C (1-200) +C (1-200) +C (1-200)	*Bact. pullorum* A
14	116	33	2 Y 3 H 3 Y	— — —	— — —	— — —	+ + +	+C (1-200) +C (1-200) +C (1-200)	*Bact. pullorum* A
15	264	71	1 Y	—	—	—	—	+C(1-200)	*Bact. pullorum* ?
16	110	46	2 Y	—	—	—	+	+C (1-200)	*Bact. pullorum* A
17	239	33	1 L	—	—	—	+	+C (1-200)	*Bact. pullorum* A
18	66	10	1 Y	—	—	—	+	+C (1-200)	*Bact. pullorum* A
19	38	11	2 Y 3 H 3 Y	— — —	— — —	— — —	+ + +	+C (1-200) +C (1-200) +C (1-200)	*Bact. pullorum* A
20	407	103	1 L 2 Y 3 Y 4 H	— — — —	— — — —	— — — —	+ + + +	+C (1-200) +C (1-200) +C (1-200) +C (1-200)	*Bact. pullorum* A

Y=unabsorbed yolk; H=heart blood; L=liver.

The results presented in this table need no comment. It can readily be seen that, with the exception of one culture obtained from flock No. 15, all cultures obtained from dead chicks which had been hatched from positive-reacting birds were maltose-dextrine-dulcite negative, and produced gas in dextrose. This is significant in that these flocks were widely distributed, and the only exception to this rule was the one noted above. This culture was maltose-dextrine-dulcite negative and was anaerogenic. At any rate, it gave none of the reactions for *Bact. sanguinarium*. On this experiment were 5,619 breeding hens and 924 were positive reactors, giving a positive agglutination up to dilutions of 1,000 and over. It is reasonable to believe that these results would be substantiated by a repetition of the experiment. While there are, as already noted, certain factors which have influenced the test and which may suggest need of modifications, — such as the validity of the agglutination tests, based on interagglutinability of *Bact. pullorum*, *Bact. sanguinarium* and other antigens in both *Bact. pullorum* and *Bact. sanguinarium* serum, — yet the fact remains that in the twenty flocks mentioned the agglutination test definitely located infection in 924 birds in a total number of 5,619. The differential characteristics of the cultures isolated from dead chicks which had been hatched from the eggs laid by these positive-reacting birds proved to be typical *Bact. pullorum*, conforming morphologically and biochemically to the standard set as a result of fermentative, serological and morphological studies completed.

After all is said about chances of error with the test, data are constantly being accumulated which indicate that the agglutination when carefully controlled through epidemiological work is at present the best method we have of locating *Bact. pullorum* infection and furnishing poultrymen a starting point for its elimination.

Summary.

From the foregoing data the following conclusions appear justified concerning the diagnosis of *Bact. pullorum* infection in the domestic fowl: —

1. From the fermentation studies conducted over a period of three years, it was found that *Bact. pullorum* is maltose-dextrine-dulcite negative and aerogenic, while all cultures of *Bact. sanguinarium* studied have been maltose-dextrine-dulcite positive and anaerogenic. These characteristics are constant. Whenever there has been question as to cultural and morphological differentiations, these investigations have shown that the biochemical tests have aided in making a final decision. Variations in morphology of the pullorum strains are frequent; therefore doubtful cultures should be submitted to the maltose-dextrine-dulcite test and checked by gas production in dextrose. Experience has shown that this procedure should be followed as a routine in all laboratories having to do with the pullorum problem.

2. From the examination of 600 avian specimens for the anaerogenic, non-motile, maltose-dextrine-dulcite positive form which produced en-

larged spleens associated with marked leukemic conditions, it was of some significance that the true sanguinarium culture was identified only six times. Chick examinations conducted during this same period, representing several hundred examinations, all yielded typical pullorum cultures. There was but one exception, and this culture was probably an atypical pullorum form which had become anaerogenic. In the examination of the adult avian specimens, the maltose-dextrine-dulcite negative forms isolated from several dead hens indicate that Hadley is correct in his contention that *Bact. pullorum* may assume a dual rôle: *Bact. pullorum* A being maltose-dextrine-dulcite negative and aerogenic, infecting young chicks; and *Bact. pullorum* B being maltose-dextrine-dulcite negative and anaerogenic, infecting adult hens. Cultures from eggs have always been aerogenic. If knowledge of *Bact. sanguinarium* is based upon the anaerogenicity of cultures, the absence of this property in cultures isolated from adult hens, chicks and eggs sent from all parts of the State would appear to indicate that fowl typhoid is not widely distributed in Massachusetts.

3. From pathological and bacteriological examination of 83 birds suffering with the so-called "paralysis," the evidence at hand does not indicate that the disease, so widely distributed at certain periods of the year, is due to the presence of the pullorum or sanguinarium type of organism.

4. The agglutination test has become a popular means of recognition in the domestic fowl of those individuals which have contracted infections in chickhood, and consequently, as adult productive fowls, may have become, through infections in their ovaries, carriers of infection to the offspring. During this investigation hundreds of agglutination tests have been made, demonstrating that there is an interagglutinability of *Bact. pullorum* with *Bact. sanguinarium*, *B. typhosus*, *B. paratyphosus* A and *B. paratyphosus* B antigens, with a consequent tendency to make the test lose in terms of specificity. The fact remains, however, as a result of experiments in this department, that in twenty flocks studied, representing 5,619 breeding birds, the test located infection in 924. Furthermore, the differential characteristics of the cultures isolated from dead chicks which had been hatched from eggs laid by these positively reacting birds proved them to be typical *Bact. pullorum*, conforming morphologically and biochemically to the standard set for this organism. Therefore, from these data, the conclusion seems justified that the agglutination test, when carefully controlled through epidemiological work, is at present the best method we have for locating *Bact. pullorum* infection and furnishing to poultrymen a starting point for its elimination.

Literature Cited.

(1) Hadley, Philip. 1918. The Colon-typhoid Intermediates as Causative Agents of Disease in Birds. 1. The Paratyphoid Bacteria. R. I. Agr. Expt. Sta. Bul. No. 174.

(2) Smith, Th., and Ten Broeck, C. 1915. A Note on the Relation between *Bacterium pullorum* (Rettger) and the Fowl Typhoid Bacillus (Moore). In Jour. Med. Research, Vol. XXXI, pp. 547–555.

(3) Smith, Th., and Ten Broeck, C. 1915. Agglutination Affinities of a Pathogenic Bacillus from Fowls (Fowl Typhoid) (*Bacterium sanguinarium*, Moore), with the Typhoid Bacillus of Man. In Jour. Med. Research, Vol. XXXI, pp. 503–521.

(4) Rettger, Leo F., and Koser, Stewart G. 1917. A comparative study of *Bacterium pullorum* (Rettger) and *Bacterium sanguinarium* (Moore). In Jour. Med. Research, Vol. XXXV, No. 3, 1916, pp. 443–458.

(5) Taylor, Walter J. 1916. An Outbreak of Fowl Typhoid. In Jour. Amer. Vet. Med. Assoc., Vol. 49, pp. 35–49.

(6) Ward, Archibald R., and Gallagher, Bernard A. 1917. An Intradermal Test for *Bacterium pullorum* Infection in Fowls. U. S. Dept. Agr. Bul. No. 517.

(7) Pfeiler, W., and Rehse, A. 1913. *Bacillus typhi gallinarum alkalifaciens* and the Disease which it causes in Fowls. Mitteilungen d. Kaiser-Wilhelms Institut f. Landwirtschaft in Bromberg, Vol. 5, pp. 306–321.

(8) Goldberg, S. A. 1917. A Study of the Fermenting Properties of *Bacterium pullorum* (Rettger) and *Bacterium sanguinarium* (Moore). In Jour. Amer. Vet. Med. Assoc., Vol. 51, pp. 203–210.

(9) Hadley, Philip, Caldwell, Dorothy W., and Heath, Bertha M. 1919. Bacteriological Notes. In Jour. Bacteriology, Vol. IV, No. 1, p. 65.

(10) Hadley, Philip. 1917. Infections caused by *Bacterium pullorum* in Adult Fowls. R. I. Agr. Expt. Sta. Bul. No. 172.

(11) Mulsow, F. W. 1919. The Differentiation and Distribution of the Paratyphoid-enteritidis Group. VI. Avian Typhoid Bacilli: a Comparative Study of *Bacterium pullorum* and *Bacterium sanguinarium*. In Jour. Infect. Diseases, Vol. 25, pp. 135–162.

(12) Krumwiede, Chas., Jr., and Kohn, Laurence. 1917. Studies on the Paratyphoid-enteritidis Group. IV. The Differentiation of the Members of the Paratyphoid-enteritidis Group from *B. typhosus*, with Special Reference to Anaerogenic Strains and Observations on the Fermentative Characteristics of the Avian Types. In Jour. Med. Research, Vol. 36, p. 509.

BULLETIN No. 210.

DEPARTMENT OF ENTOMOLOGY.

INJURY TO FOLIAGE BY ARSENICAL SPRAYS.

II. CALCIUM ARSENATES AND ARSENITES.
III. NOTES ON OTHER ARSENICALS.

BY H. T. FERNALD AND A. I. BOURNE.

In Bulletin No. 207 of this station the effects of lead arsenate sprays on foliage were discussed. In a similar way this bulletin gives the results of studies with calcium arsenates and arsenites, and the factors which appear to cause foliage injury following their use, together with notes on other arsenicals.

As in the case of the lead arsenates, the chemical work was done under the supervision of Dr. E. B. Holland of the Department of Plant and Animal Chemistry of the Experiment Station, and the applications of the materials and studies of the results were made by the Department of Entomology. All the statements made in Bulletin No. 207 with reference to responsibility for the various parts of the work, methods of application, and adequacy of methods, apply also to this part of the investigation.

II. CALCIUM ARSENATES AND ARSENITES.

Materials.

Pure Acid Calcium Arsenate. — To obtain pure calcium arsenate from manufacturers proved impossible, and a quantity of this substance was finally prepared by the Department of Plant and Animal Chemistry of this station. It was the acid arsenate ($CaHAsO_4 . H_2O$) and was a white powder consisting of rhombic crystals varying in size and with about 1 per cent of them broken. Analyzed, it gave the following: —

	Air Dry.	Dried.
Water	.120	–
Calcium oxide, CaO	28.300	28.334
Arsenic pentoxide, As_2O_5	57.955	58.025
Water of combination	13.630	13.646
	100.005	100.005

The powder, therefore, was a practically pure acid calcium arsenate. This substance proved very soluble on standing twenty-four hours, 44.82 per cent of the arsenic pentoxide entering into solution. The addition of milk of lime to the material was therefore tried, and after 1 per cent of this had been added, the amount dissolved was only .17 per cent. As finally used, the spray was accordingly prepared as follows: —

Four pounds of quicklime were slaked in about 40 gallons of water, just enough water being added at a time to maintain a brisk action without "drowning" the lime. After the slaking was completed, enough more water to make 50 gallons in all was added. Eighty-five hundredths of a pound of the arsenate was then mixed in, this being the amount calculated as necessary to give the spray the same strength of arsenic pentoxide as that of the lead arsenate sprays, in order to make the tests comparative. The material was strained into the spray pump and kept well agitated.

Commercial Calcium Arsenate. — This was a bulky, white powder consisting of minute spherical particles. It was purchased in the market, and on analysis proved not to be similar to the pure material considered above, but a combination of calcium and arsenic acid, with a considerable excess of lime. It might, perhaps, be fairly described as a basic lime arsenate. Its analysis gave —

	Per Cent.
Water, H_2O	1.38
Water in combination and occluded	2.92
Ferric and aluminum oxides	1.30
Calcium oxide, CaO	45.47
Magnesium oxide, MgO	.68
Sodium oxide, Na_2O	1.09
Arsenic pentoxide, As_2O_5	46.61
Sulfur trioxide, SO_3	.18
Chlorine, Cl	.02
Soluble silica, SiO_2	.16
Acid insoluble matter	.13
	99.94

This was not a pure material, but the impurities were not of such a nature nor present in such amounts as to be likely to cause injury to foliage.

Tests of the solubility of this material gave only a trace of arsenic pentoxide as dissolving after twenty-four hours' treatment with water. In order to make a direct comparison of this substance with the pure acid salt, milk of lime was added as described above, and 1.14 pounds of the arsenate were used for each 50 gallons of spray, this amount providing enough arsenic pentoxide to equal that used in the other tests.

Calcium Metarsenite. — Two samples of this material (both pastes) were tested, having been received from manufacturing companies. Their analyses follow: —

I.

	Per Cent.
Water, H_2O	67.87
Calcium oxide, CaO	6.78
Arsenic trioxide, As_2O_3	23.87
Arsenic pentoxide, As_2O_5	.09
Magnesium oxide, MgO	.05
Sodium oxide, Na_2O (estimated)	.70
Chlorine, Cl	.80
Insoluble matter	.01
	100.17

The original composition of this material was probably about as follows: —

	Per Cent.
Water, H_2O	67.87
Calcium ortho arsenate, $Ca_3\ (AsO_4)_2$	.18
Calcium metarsenite, $Ca(AsO_2)_2$	30.31
Magnesium metarsenite, $Mg(AsO_2)_2$	.30
Sodium chloride, $NaCl$	1.32
Insoluble matter	.01
	99.99

This substance gave 11.58 per cent of soluble arsenic trioxide on standing in water for twenty-four hours, showing at once its dangerous nature when applied to foliage. When mixed with milk of lime, however, the amount soluble was greatly reduced, but even then safety could not be obtained with any certainty.

II.

	Per Cent.
Water, H_2O	79.03
Arsenic trioxide, As_2O_3	16.20
Arsenic pentoxide, As_2O_5	.03
Calcium oxide, CaO	4.51
Magnesium oxide, MgO	.05
Sodium oxide, Na_2O (estimated)	.07
Chlorine, Cl	.03
Organic matter, etc.	.08
Insoluble matter	.01
	100.01

The original composition of this material was probably substantially as follows: —

	Per Cent.
Water, H_2O	79.03
Calcium ortho arsenate, $Ca_3(AsO_4)_2$	.06
Calcium metarsenite, $Ca(AsO_2)_2$	20.34
Magnesium metarsenite, $Mg(AsO_2)_2$	.30
Sodium arsenite, $NaAsO_2$	.13
Sodium chloride, NaCl	.05
Organic matter, etc.	.08
Insoluble matter	.01
	100.00

The arsenic in this material, also, proved so soluble on standing in water as to make it unsafe for application to foliage. It was tested both in water alone and with the addition of various percentages of milk of lime. With both samples, enough was taken to give the standard amount of arsenic, so that the treatments should be comparable with those made with the lead arsenates and lime arsenates.

Experimental Work.

The materials described above were sprayed upon the apple, cherry, peach, pear, plum and elm, under the same conditions as given in Bulletin No. 207, and the results obtained follow.

Pure Acid Calcium Arsenate with 1 Per Cent Milk of Lime. — The apple, sprayed with this material in clear weather, shows injury above the safety line (Fig. 1, AB), from high temperature with low humidity to low temperature with high humidity. The line for the greater part of its course runs lower than the safety line for lead arsenates, though at the high humidity end the reverse is true to a slight degree. As the general safety line for the apple is much below most of those given in clear weather, the difference is more marked by comparing any of the clear weather lead arsenate safety lines in Bulletin No. 207 with Fig. 1, than when the general one is used. The evidence is that pure acid calcium arsenate with 1 per cent milk of lime cannot be used on the apple at as high temperatures and humidities as the lead arsenates in clear weather. This is true, also, for cloudy weather, though the difference is not so great.

On the pear, clear-weather tests gave six cases of injury above the safety line (Fig. 2, AB), which runs considerably higher than in the case of the apple. In the cloudy weather tests (Fig. 2, CD), as was the case with the lead arsenates, the pear is evidently much more resistant to spray injury than the apple.

In the case of the cherry (Fig. 3), the leaves are more liable to injury than the apple, but less so than the plum. The cloudy weather safety lines for the cherry and plum (Figs. 3 and 4, CD) are very nearly the same, however. With the plum, temperature seems to play an important part, injury beginning in clear weather at quite a low point, while high humidity seems to be less dangerous (Fig. 4, AB).

SAFETY LINES FOR SPRAYING WITH PURE ACID CALCIUM ARSENATE.
AB, clear weather; CD, cloudy weather.

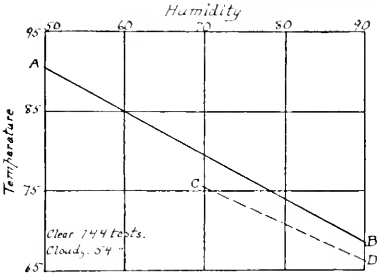


FIG. 1. — Apple.

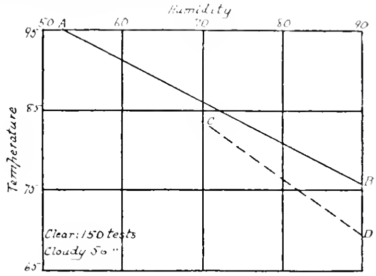


FIG. 2. — Pear.

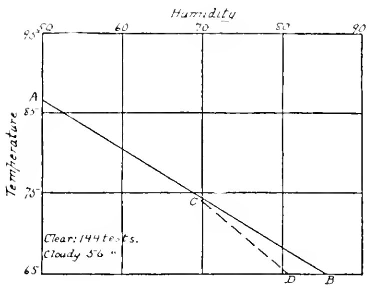


FIG. 3. — Cherry.

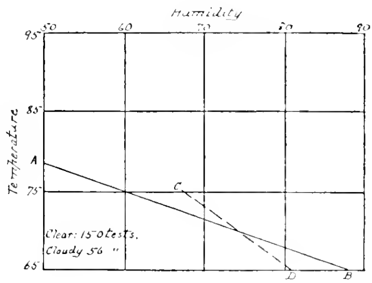


FIG. 4. — Plum.

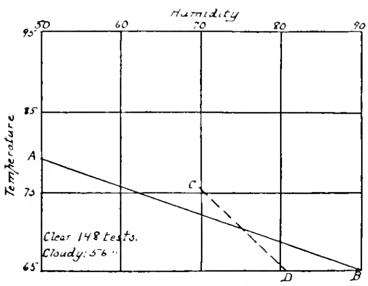


FIG. 5. — Peach.

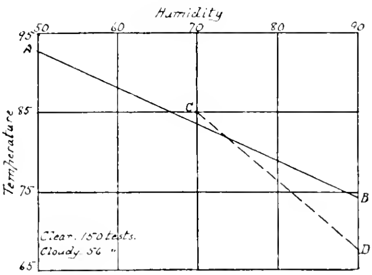


FIG. 6. — Elm.

The peach (Fig. 5) quite closely follows the plum in its resistance to calcium arsenate, and the two figures (4 and 5) show no more difference than might perhaps easily disappear could a greater number of tests have been made.

The elm (Fig. 6) is evidently less resistant to pure acid calcium arsenate than the pear, as eleven cases of injury were obtained above the safety line AB of the figure, in clear-weather tests, and the line itself runs considerably lower than that for the pear. In cloudy weather the elm also appears to be more easily injured at high humidities, even if the temperature is low.

Commercial Calcium Arsenate with 1 Per Cent Milk of Lime. — On the apple (Fig. 7) this material gives results differing little from those obtained with the pure acid calcium arsenate described above. The cloudy weather tests suggest a little greater safety with the commercial material at medium combinations of temperature and humidity, but the rather small number of tests obtained makes this difference less significant than if similar results had been shown by a larger number.

In the case of the pear (Fig. 8) no injury was obtained following any of the tests, and AB is simply placed along the highest tests obtained. Whether higher combinations of temperature and humidity would have shown injury could they have been obtained, is, of course, unknown. The cloudy weather safety line CD is more satisfactorily located, three cases of injury having shown that the line could not be placed higher.

Tests of the cherry (Fig. 9) give in general an agreement between the two materials (compare Figs. 3 and 9), though the commercial substances seem, as in the case of the apple, to be a little safer at medium combinations of temperature and humidity.

With the plum (Fig. 10) it would seem that the commercial material can be used with safety at a considerably higher temperature than the pure when the humidity is low (86° as compared with 79° at 50° humidity). Aside from this, nothing of significance appears on comparing Figs. 4 and 10.

On the peach (Fig. 11) the two materials give almost identical results (compare Figs. 5 and 11). On the elm (Fig. 12) the commercial article appears to be safer in clear weather than the pure substance (compare Figs. 6 and 12), although one doubtful injury at 85° humidity suggests that the point B on Fig. 12 may be too high.

Comparison of the safety lines obtained on the different kinds of foliage tested with commercial calcium arsenate in clear weather brings out several points of interest. The elm (Fig. 13, 2) would at first seem to be more resistant than the pear (1), particularly at high T and low H. It should be remembered, however, that line 1 was located along the highest tests obtained, no injury showing up to that line, and no tests being available above it. It is not improbable that this line could go considerably higher than where it is now located. The cherry (4) is more resistant than the plum (5) at high T, but slightly the reverse holds at high H, and both,

SAFETY LINES FOR SPRAYING WITH COMMERCIAL CALCIUM ARSENATE.
AB, clear weather; CD, cloudy weather.

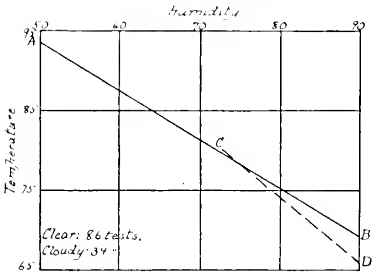


FIG. 7. — Apple.

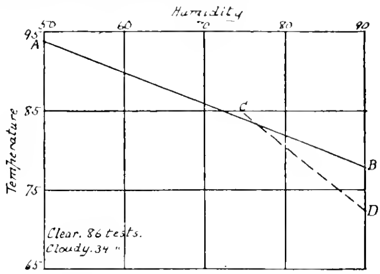


FIG. 8. — Pear.

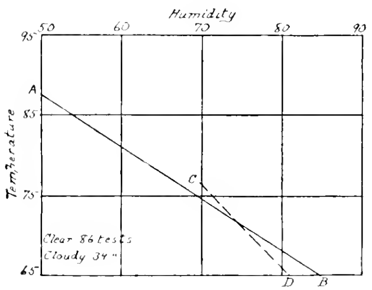


FIG. 9. — Cherry.

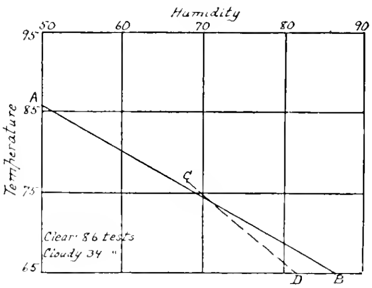


FIG. 10. — Plum.

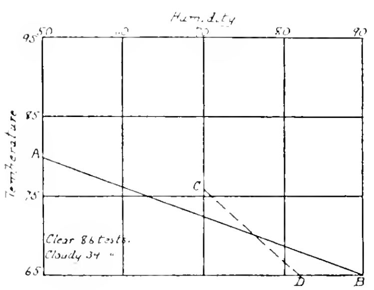


FIG. 11. — Peach.

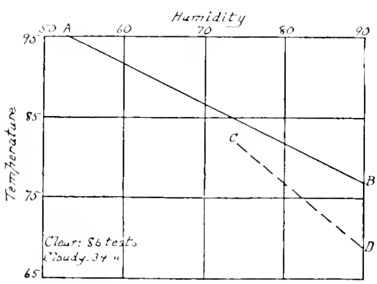


FIG. 12. — Elm.

at this end of the figure, are less resistant than the peach (6), though at high T the latter is considerably less resistant than the other two.

In cloudy weather (Fig. 14) the pear, elm and apple show about the relative relations to each other that would be expected from the studies on lead arsenates, while the cherry, plum and peach are almost identical for the high H limit of safety, and nearly so at the other ends of their safety lines. Such differences as they do show might easily disappear were more tests available, though, on the other hand, such tests might have led to greater differences.

Finally, it is evident that there is a wide difference in the safety lines, and that the spraying of different kinds of trees cannot always be done with safety on the same day. It may be perfectly safe to spray apples on a day when spraying plums, peaches or even cherries might prove disastrous.

Calcium Metarsenite. — The two samples of this substance described above, produced injury on the foliage of all the kinds of trees tested, within two or three days after the application, the injury increasing until the leaves were practically destroyed and dropped off. Though the addition of milk of lime appeared to bring down the solubility of the arsenic within reasonable safety limits in laboratory tests, this did not appear to hold under field conditions, even when the milk of lime was increased to 3 per cent, so further investigation of this material was given up.

III. NOTES ON OTHER ARSENICALS.

Magnesium Arsenate. — This substance, sent in by an insecticide manufacturing company for trial, was tested on the same basis as the other materials. Two hundred and eight clear-weather tests were made at temperatures and humidities ranging from T92 H54 through T86 H70 and T80 H80 to T77 H81, for the high limits, and as low as T78 H55 and T67.5 H 69. In every case, no matter how low T and H were, injury developed on all the trees except the pear and one or two tests on the elm. Apparently, spraying with magnesium arsenate is unsafe at almost any combinations of T and H, except on the pear, where the higher combinations become unsafe, and possibly on the elm, where at low combinations only traces of injury were evident.

In cloudy weather 108 tests were made at combinations of T and H as low as T73 H76 and T67 H72, and as high as T82 H74, T78 H84 and T68 H90. In every test injury, often very serious, followed, except in two instances on the pear.

As a general conclusion from these tests, therefore, magnesium arsenate is not a safe material for spraying under any conditions.

Zinc Arsenite. — Two samples of this material, received from different manufacturers, were tested in 1913. Both were finely divided, bulky powders, light and "fluffy." They were applied, at the rates of 1 pound and $1\frac{1}{2}$ pounds in 50 gallons of water, to the same kinds of trees as were

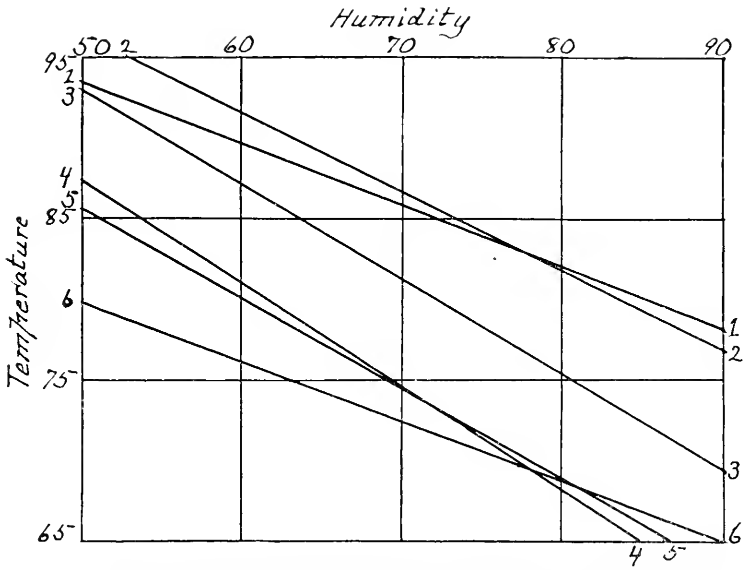


FIG. 13. — Safety lines for spraying with commercial calcium arsenate in clear weather: 1, pear; 2, elm; 3, apple; 4, cherry; 5, plum; 6, peach.

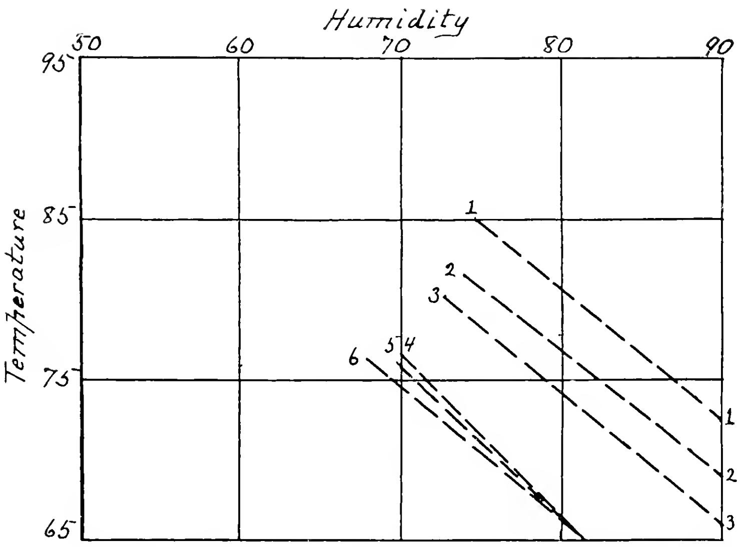


FIG. 14. — Safety lines for spraying with commercial calcium arsenate in cloudy weather: 1, pear; 2, elm; 3, apple; 4, cherry; 5, peach; 6, plum.

used for the other tests, and in every case injury followed, generally severe. Clear or cloudy weather seemed to give little difference in the results, and spraying at low T and H combinations produced injury as certainly as with high combinations of these factors. Extensive tests of zinc arsenite, therefore, were not continued.

SUMMARY.

1. Pure acid calcium arsenate is not on the market. Tests with it indicate in a general way that the same factors determining injury to foliage hold good as with the lead arsenates, but that the safety lines run lower.

2. With commercial calcium arsenate the safety lines run about as high (in some cases a little higher) as with the pure material, but lower than with the lead arsenates. In the case of the peach, however, the safety line does not differ greatly from that obtained with the lead arsenate powder.

3. It is possible that the excess of lime in the commercial calcium arsenate may be sufficient to prevent the arsenic pentoxide from entering into solution. Further tests are needed on this point, as considerable time and bother can be saved if the addition of milk of lime is unnecessary.

4. In general, lime arsenate does not give as satisfactory results as the lead arsenates, the range of T and H combinations at which it is safe being more limited.

5. The spraying of different kinds of trees with commercial calcium arsenate cannot always be done with safety on the same day. The treatment may be safe on some kinds of trees under conditions which make it dangerous to others.

6. Calcium metarsenite is not safe for use on fruit tree foliage.

7. The same is true for magnesium arsenate and zinc arsenite — at least for the samples tested.

BULLETIN No. 211.

DEPARTMENT OF POULTRY HUSBANDRY.

CHANGES IN EGG PRODUCTION IN THE STATION FLOCK.

BY H. D. GOODALE AND RUBY SANBORN.

Introduction.

For the past eight years the work of the Massachusetts Agricultural Experiment Station with poultry has centered about the problem of breeding better layers. A certain measure of success has been reached. The present paper is a descriptive history of the work. The theory that is under test, the plan of procedure, the results secured to date, with such comment as seems to be required to prevent misinterpretation of the data, with such suggestions as can be offered to the breeder, are presented.

The Working Hypothesis.

The studies were begun in December, 1912. It was then supposed that the inheritance of fecundity was a simple two-factor Mendelian matter, but it was not long before it gradually became clear that, with Rhode Island Reds, the egg record made by a bird was the result of the combined action of a number of inheritable characteristics.

Simplifying matters as much as possible, five main characteristics may be recognized, namely: —

1. Maturity.
2. Rate (intensity).
3. Broodiness.
4. Point at which production ceases (persistency).
5. Winter pause.

Each component is very variable. Resulting egg records from combinations of these five variable characteristics are illustrated in Figs. 1 and 2. In Fig. 1 are used the two extremes only of each of the five components, which make 32 possible combinations, each illustrated by an actual

Fig. 1. — Typical Egg Records.

Illustrative of the part played by several factors in determining the number of eggs laid.

BAND NUMBER	FORMULA	DATE HATCHED	AGE AT FIRST EGG	NUMBER EGGS PER MONTH SEP	OCT.	NOV	DEC.	JAN	FEB.	MAR	APR	MAY	JUN.	JUL.	AUG.	SEP	OCT.	NOV	365 DAYS	TOTAL
B 357	ENFCA	MAR 25	187	3	25	25	19	22	18	24	21	27	28	22	28	26	17		286	305
B 8324	ENFCQ	APR 4	192		10	19	23	19	18	24	21	23	23	25	23	10			238	238
B 8560	ENFPA	APR 11	185		12	23	18	20	1	25	25	27	22	26	23	23	12		254	257
B 8355	ENFPQ	APR 4	177	3	20	22	26	4	16	18	21	26	25	22	25	6			232	232
B 8336	ENSCA	APR. 4	185		11	21	18	16	14	18	16	16	16	19	20	18	8		206	211
B 3033	ENSCQ	MAR. 31	193		15	10	14	15	16	19	17	20	12	9					147	147
B 24	ENSPA	MAR 18	191	4	22	9	1	13	13	18	20	17	15	18	17	17	10		181	194
B 4440	ENSPQ	MAY 5	187			10	16	12	10	13	13	17	9		15	4			119	119
8490	EBFCA	APR 30	170		13	26	29	25	20	21^{B}	17	$^{B}12$	$^{B}14$	$^{B}14$	$^{B}1$	12	8		210	212
B 3245	EBFCQ	APR 7	182		23	14^{B}	25	$^{B}6$	19^{B}	18	$^{B}16^{B}$	14^{B}	12^{B}	13	10^{B}				170	170
B 8008	EBFPA	MAR 28	194		8	25	22	5	15	25	$^{B}15^{B}$	15^{B}	15^{B}	$^{B}7$	$^{B}13$	$^{B}9$	$^{B}6$	7	190	197
B 2885	EBFPQ	MAR. 31	182	1	27	18		17	21	22	25	25	$^{B}9$	20^{B}					185	185
8751	EBSCA	MAY 7	193			11	10^{B}	17	$^{B}11$	12^{B}	16^{B}	12^{B}	12^{B}	11	9	$^{B}0$	4		135	135
B 2185	EBSCQ	MAY 3	197			2	18	16	16	20	17	9^{B}	10^{B}	8	$^{B}3$	13^{B}			132	132
B 2907	EBSPA	MAR. 31	190		4		12	18	15	8	14	17^{B}	21	19	$^{B}7$	11	11		150	150
B 4512	EBSPQ	MAY 5	189			8	19		15	$^{B}11$	$^{B}9$	$^{B}1$	$^{B}3$	5^{B}					81	81

B8080	LNFCA	MAR 28	217		1	20	22	19	19	22	22	25	25	24	26	20	17		262	262
B9028	LNFCQ	APR 25	221				23	22	15	22	22	26	24	23	14				191	191
B8105	LNFPA	MAR 28	221			20	23	4	21	24	27	28	22	24	22	19	14		248	248
B9027	LNFPQ	APR 25	217			2	6	25	21	26	27	29	22	24	14				196	196
B587	LNSCA	APR 1	248				17	17	15	15	17	17	1	16	1	18	10		144	144
8087	LNSCQ	APR 9	217			8	19	15	13	14	10	12		6	2				99	99
B63	LNSPA	MAR 18	203		14	19	5		7	10	16	19	15	19	20	16	2		162	162
B3089	LNSPQ	APR 7	292					1	5	10	18	10	3						47	47
119	LBFCA	MAR 23	246			5	26	24	25	27	19B	15B	14	B13	B14	B14B	12		208	208
B4082	LBFCQ	APR 28	240				5	24	24	24	B20	B16	B14	B13	B10	B8			158	158
7918	LBFPA	APR 2	226			1	14	25	2	22	28	B15B	6B	10B	9	5	11		148	148
B2818	LBFPQ	MAR 31	234			8	17		11	28	25	25	24	13	20B				171	171
803	LBSCA	APR. 27	228				14	15	14	15	11B	9B	7	B4		6	10		105	105
8602	LBSCQ	APR. 30	227				13	17	17	13	15B	16B	13	B	19				123	123
7697	LBSPA	MAR 19	268				6	19	3	12	16B	B6	B9	9B	17	4	8		119	119
8941	LBSPQ	MAY 14	254					4	3	19	12B	6B	7B						51	51
B1209	LNS-Q	APR 22	274					1	1		1		2		2	2			9	9
B1202		APR 22																	0	0

Legend: E, early (laid before 201 days of age); B, broody; F, fast (usually laid at the rate of more than 21 eggs per month); P, winter pause of ten or more days; A, persistent (continued production later than September 30); L, late (laid after 200 days of age); N, not broody; S, slow (usually laid less than 22 eggs per month); C, continuous (no winter pause); Q, quitter (stopped laying before October 1). Classification of broody birds in respect to rate is based on the non-broody months. For certain combinations it has not been possible to find records that fit the definitions closely in all respects. The horizontal lines indicate periods over which production extended; a pause of ten or more days is shown by a break in the line; B above the break indicates a broody pause. Under the heading Total is given the production for the biological laying year, which sometimes exceeds the 365-day year.

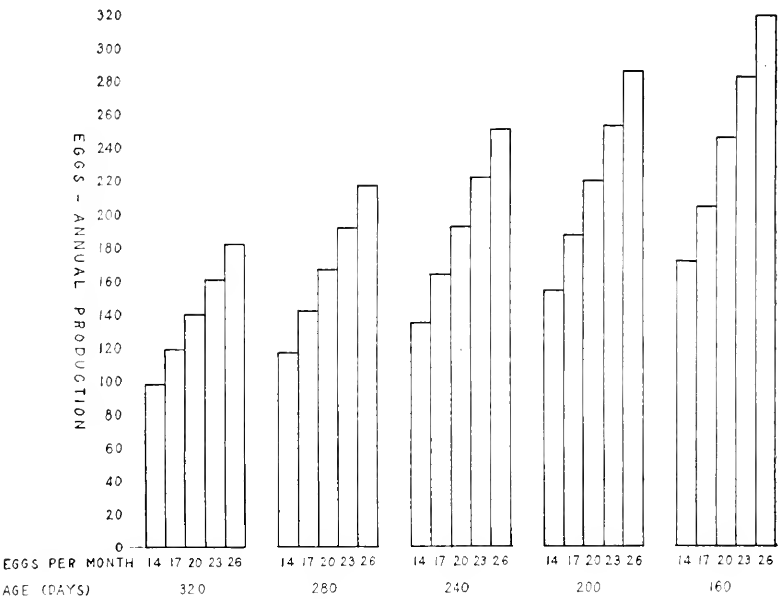


FIG. 2. — The Effect of Variation in Two Factors.

Five points of maturity and rate are chosen, and it is assumed that each bird was hatched April 15, was non-broody, was without winter pause and stopped laying September 30.

record. Fig. 2 was made by choosing five points of the first and second characteristics (maturity and rate), assuming that the other three remain unchanged, and showing by artificial records what would be the resulting yearly production. If all the variations of all the characteristics were combined in all possible ways, the number of different egg records secured would be in the thousands.[1] Environment is also responsible for much variation in production.

If the records of the highest producing hens are examined, it is to be noted that they begin early in life (and also fairly early in the season) and continue at a steady and relatively high rate throughout the twelve months. Examined from the negative standpoint, it is noticed that there are no broody pauses, no winter pause, no delay in beginning production, no early cessation of production, no slow rate while laying. A record at the low end of the series is zero, but one only shortly removed shows late maturity, early cessation and slow rate. The problem of the breeder, then, is to devise a method of eliminating the undesirable characteristics from the flock and of securing fairly uniform high production.

[1] It is a point of considerable importance to recognize that the greatest complexity occurs in those records near the mode of the egg production curve, and that those records near each extreme are less complex, so that studies made on a flock composed of either very high or very low producing birds will be simpler than if made on flocks of average production.

As long as attention is fixed solely on the number of eggs laid, and no recognition given to the fact that the difference between a 150-egg hen and a 200-egg hen is something more than just 50 eggs, progress in getting at the fundamentals of the inheritance of egg production is hindered. The solution of the problem demands that the inheritance of each component be ascertained by specially planned experiments. This would require about fifty years of one man's time, with a flock of 500 pullets trapnested through their first laying year.

The policy which was therefore adopted at this station was, using as a working theory the concept of an egg record as briefly outlined above, to establish a high-producing strain by improving the flock step by step, making it fairly homogeneous for one of the five characteristics and then for another. In this way there would eventually be built up a flock which would meet the standards required for the highest production. At the same time it was planned to make an intensive study of broodiness and to collect data on the other characteristics, with the purpose of gaining as much useful information as possible.

Plan of Procedure.

The Foundation Stocks.

The foundation stock as a whole proved deficient in desirable characteristics. The birds were late maturing and, when hatched in April or May, did not begin laying till midwinter. Many stopped producing by midsummer or soon after. The winter pause was present but not conspicuous because of the late start made. Rate of production while laying was excellent. The birds were deficient in vitality and were poor breeders. It was essential, of course, to remedy these last two defects before further work could be done. Stock of good vitality was added, but unfortunately the general satisfactory rate of production was lost and the winter pause accentuated, so that, as the next paragraph shows, ground was lost for the time being. (See Fig. 5, p. 109.)

The members of the flock hatched in 1915 were, on the whole, late maturing and broody, and exhibited a well-marked winter pause in early layers, a slow rate, and a tendency to stop production early in the summer. There were, however, individuals which matured early, others that were not broody, some that laid at a high rate, some that persisted in production till late fall, and some that lacked a winter pause. Individuals exhibiting various combinations of these characteristics also occurred, but there were none in which all the desired characteristics were combined. This was to be accomplished by breeding, and the present plan of procedure, vaguely formulated the year before, was put into active practice.

Basis of Selection of Breeding Females.

Beginning in 1916, female breeders were selected primarily for early maturity, and late maturing individuals used only when exceptional in other respects. A fair approach to the objective was obtained in the

laying flock of 1917–18, partly through a fortunate nick between a single pair.

Meanwhile, the intensive work on broodiness had given a flock comparatively free from broodiness, so that it was known that broodiness could be very much reduced even if not eliminated. The next step was an attempt to fuse the low-broody strain, which were poor producers, with the early maturing line, which were good layers, by choosing non-broodies from the latter and good layers from the former. Of course, it was expected that the fusion would result in a temporary setback. The first year after the fusion, 1919–20, fewer eggs were laid and more broody birds occurred in the combined flocks than in the respective contributing strains, but this difficulty has been overcome. On reviewing the situation, it is clear that the desired objective would have been reached had the non-broody members of the high line alone been used, for these birds are the ones that constitute the major portion of the ancestry of to-day's flock.

While concentrating on maturity and broodiness, some progress has been made in eliminating the winter pause, and in securing larger numbers of birds that lay at a high rate. Data covering these statements are given in later sections of the paper. The proportion of birds in the flock that approach the desired type is much greater. With the increase in the number of birds approaching the desired type, birds with records that would have qualified them for breeders in the early stages of the work are now rejected. The basis of selection has been progressively altered and selection made progressively more stringent, as shown in Fig. 3 and Table I.

TABLE I. — *Data on the Mothers of the Several Flocks.*

Mothers of Pullets Hatched in —	Mean Age at First Egg.		Mean Winter Production.		Mean Annual Production.	
	Number of Birds.	Days.	Number of Birds.	Eggs.	Number of Birds.	Eggs.
1913	-	-	72	26.72	42	123.52
1914	36	252.89	59	40.17	49	141.02
1915	89	253.45	118	29.07	92	122.62
1916	60	228.60	61	47.38	57	147.72
1917	40	198.93	39	76.18	36	186.36
1918	25	193.08	25	92.76	22	204.41
1919	29	199.79	29	85.69	28	222.68
1920	38	197.71	37	84.78	16	228.06

In each case those mothers only are included having daughters with a corresponding record. Because of the clean-up in June, 1920, an exception is made so that the annual production for 1919 is for birds having daughters that laid up to June 1. For the first four years birds of the original stock whose hatching date is unknown were used in decreasing numbers as breeders, which accounts for the small number of birds whose mean age at first egg is given.

Other qualifications besides those exhibited in the egg records are required. A hen is a good breeder only if she produces such a number of pullets that they constitute a satisfactory index of her capacity (with a given mate) to transmit her own good laying qualities. Small families are undesirable, because they are often an inadequate sample of a bird's real breeding quality. As soon as it appears that a breeder's eggs are not hatching well, she is taken from the breeding pen and her offspring discarded. A few breeders are discarded for other defects, such as low vitality of their progeny.

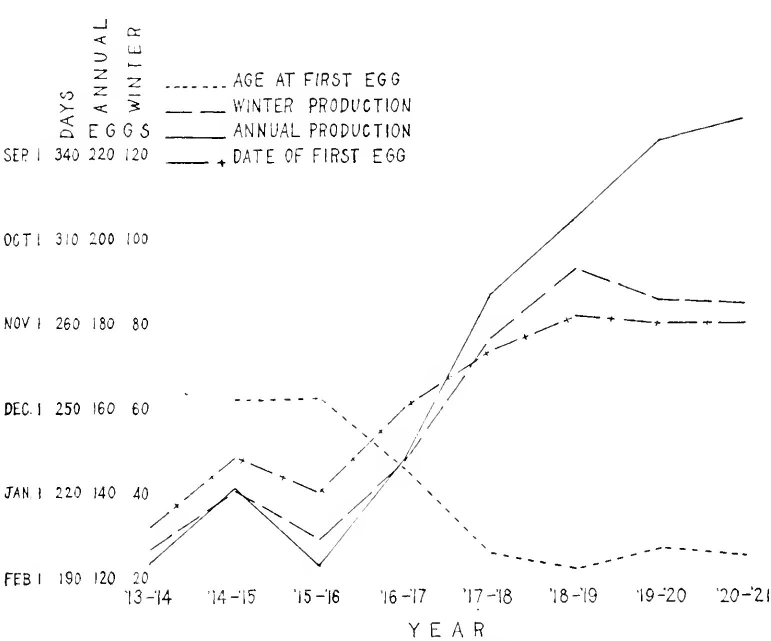


Fig. 3. — Mean Production of Female Breeders.
(From data given in Table I.)

Basis of Selection of Breeding Males.

The selection of suitable males is quite simple. First, each one comes from a large family and is the strongest, the most vigorous and usually the largest member of the group; second, he comes from a good mother; and third, the most important point of all, his sisters must have made good records.[1] The family which produces the largest proportion of females capable of qualifying as breeders is the first choice for one or more males. Naturally, males will be chosen from several families and always such as stand highest in desired characteristics.

[1] This involves keeping one or more representatives of each family till his sisters' records are available.

Continued Use of Breeders on the Basis of the Performance of their Offspring.

Birds used as breeders are kept till the records of their progeny are at hand. Many fail to transmit the desired qualities, either wholly or to a sufficient number of their progeny, and therefore are discarded. Exceptions are sometimes made with females that are otherwise remarkable, in the hope that they may nick better with another mate. Those birds that show pronounced ability in producing offspring that make egg records of the desired type may be bred several years in succession. The importance of a very few birds of this sort cannot be too greatly emphasized, for through these progress is made.

Points in Management that affect the Results.

A few points in the handling of the flocks need especial emphasis, as they bear directly on the interpretation of the results.

Flock Number. — Throughout these experiments the pullets have been kept in relatively large flocks, 100 to 125, while making their records, with the following exceptions: in 1912–13 there were two pens of 72 birds each; in 1913–14 there was one pen of 72 birds and several smaller groups of 25 to 35 each; in 1914–15 the pedigreed pullets were in large flocks, but the new stock was in smaller groups. The latter are excluded from the averages. Some years the high-line birds, or part of them, have been penned by themselves; other years they have been scattered through the flock. They have received exactly the same treatment that was given the rest.

The selection of the pullets that are put into the laying pens is based on the family. The best families having been decided upon, all the daughters in those families are included except those of exceedingly poor vitality, amounting to less than 5 per cent. As far as possible, families (offspring of one mother) containing fewer than seven daughters each are excluded. This has been done in order to enable a fair judgment of the breeding ability of any mother to be made. An exception was made to this rule in 1920–21, when all daughters weighing less than 3 pounds 6 ounces at four months of age were excluded. The effect of such exclusion, if any, on egg production is slight, as shown by correlation tables.

The time of year in which a flock of birds is hatched is one of the most important factors in determining the number of eggs laid. This is illustrated in several figures and tables, of which Fig. 13 (page 117) may be especially cited. Note that the late hatched flock loses about two months' production, — a production that, as far as the records show, is not compensated for, except in slight measure, at other seasons.

It is the practice at this station to hatch weekly. The length of the hatching season has varied from year to year, but, unless otherwise stated, only records made by birds hatched between March 25 and May 14, inclusive, are presented in this paper. The mean hatching date is April 18, from which the several yearly means vary little as shown by Table II.

TABLE II. — *Data on the Flocks of 1912–20.*

PULLET YEAR.	Hatching Date.[1]		Date of First Egg.		Age at First Egg.			Winter Production.			Annual Production.		
	Mean.	Change from 1913 (Days).	Mean.	Change from 1912 (Days).	Number of Birds.	Mean Number of Days.	Change from 1913 (Days).	Number of Birds.	Mean Number of Eggs.	Change from 1912 (Eggs).	Number of Birds.	Mean Number of Eggs.	Change from 1912 (Eggs).
1912–13	–[2]	–	Jan. 19	0	–	–[2]	–	138	28.39[3]	0.00	123	114.38	0.00
1913–14	Apr. 19	0	Dec. 31	—19	168[4]	255.61	0.00	171	36.44	+8.05	171	123.64[5]	+9.26
1914–15	Apr. 19	0	Jan. 26	+7	115	282.80	+27.00	113	13.27	—15.12	80	103.25	—11.13
1915–16	Apr. 18	—1	Jan. 7	—12	224	264.27	+8.66	237	29.44	+1.05	208	121.70	+7.32
1916–17	Apr. 19	0	Dec. 5	—45	329	229.71	—25.90	328	42.46	+14.07	294	133.67	+19.29
1917–18	Apr. 17	—2	Nov. 16	—64	291	212.96	—42.65	280	59.40	+31.01	237	165.85	+51.47
1918–19	Apr. 19	0	Oct. 30	—81	141	194.44	—61.17	109	63.45	+35.06	64	169.19	+54.81
1919–20	Apr. 20	+1	Nov. 18	—62	157	212.04	—43.57	124	58.23	+29.81	–[6]	–[6]	–[6]
1920–21	Apr. 12	—7	Oct. 29	—82	168	199.99	—55.62	160	67.65	+39.26	109	199.73	+85.35

[1] Mean hatching date based on birds that completed the winter.

[2] Mean hatching date and mean age at first egg not known for 1912.

[3] Five eggs arbitrarily added as November's quota, since trapnesting was not begun until December.

[4] Is less than 171 because of birds that never laid; kept through winter but not through year.

[5] Because of limited facilities, only 59 birds in 1913–14, hatched between the limiting dates, were trapped throughout the year. They were a selected group with an average winter production of 41.92 eggs against 36.44 for the entire flock, which, therefore, has a probable mean annual production of 123.64 eggs.

[6] Records stopped June 1. See p. 108.

Successive years do not represent successive generations. The later years include the offspring of selected parents belonging to several generations.

Floor eggs are excluded from all the data used in this paper. Artificial lighting has not been used.

Because of the prevalence of disease, the whole plant, both college and experimental, was given a thorough cleaning during the summer of 1920. All adult birds were disposed of June 1, so there are no annual records for that year.

Seasons at which Increased Production is most Desirable.

The average well-cared-for flock of pullets of American breeds begins production some time in late fall or early winter, reaches its maximum

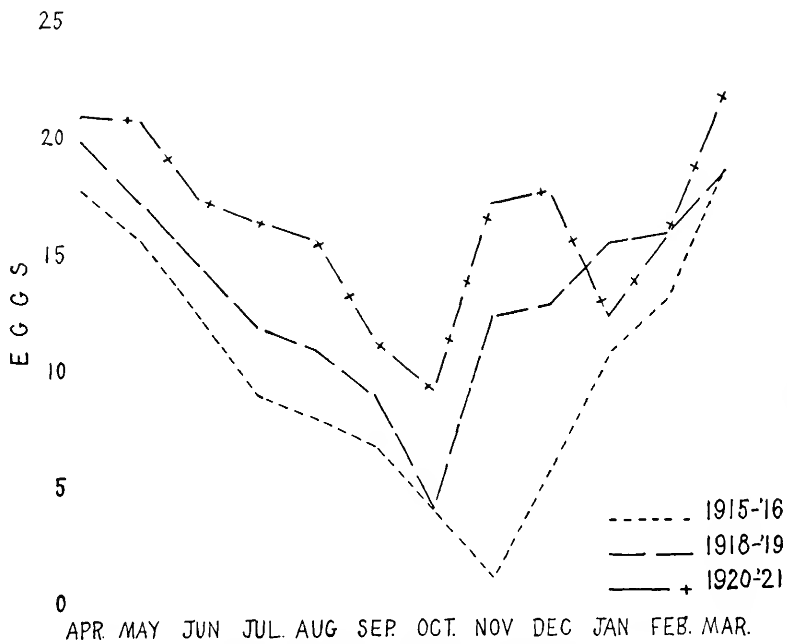


FIG. 4. — Seasonal Distribution of Production.

The right-hand part of the curve beginning with November precedes, chronologically, the left-hand portion. This arrangement emphasizes lack of production in certain months.

in March or April, and then declines more or less rapidly toward zero the following autumn, as represented in Fig. 4. The curve starts at the high point in April and ends at the high point in the preceding March, instead of starting with the beginning of production, as is customary. This arrangement emphasizes the hollow between the two high points. It is clear that if good production can be obtained in October, November and

December it should not be hard to improve production in other months, where necessary. Hence, emphasis is laid on winter production, so called, as at this season eggs bring two to two and one-half times the price paid in April. The producer who can secure a 50 per cent yield in those months will reap the reward due to his ability, at least in the immediate future, while if the methods by which such a yield is obtained become common practice, the consumer will benefit through lower prices and steady supply. While the producer may not continue to reap the harvest due to pioneer methods, his business will be on a firm basis, with the period of all outgo and no income eliminated.

The desirability of increased fall and winter production is made clearer by a comparison of the station flocks with certain farm contest flocks in Missouri as reported by Townsley (1920). The latter's average November production for the last four years ranges from 2.0 to 2.5 per hen, being 2.3 eggs each for nearly 25,000 birds in 1920. The best flock of 124 birds averaged 8.1 eggs each. On the other hand, a flock of high-line birds of similar size at this station averaged 18 eggs each. If all the flocks of the country were as good layers as this particular flock, — and there is no biological reason why they should not be, — it is apparent that both consumer and producer would benefit.

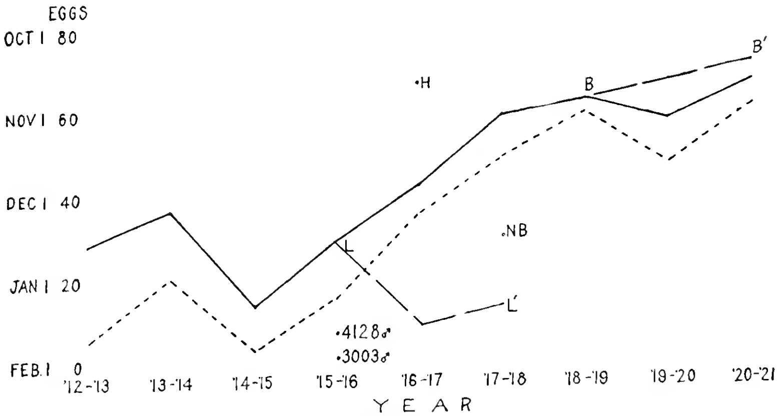


Fig. 5. — Winter Production and Date of First Egg for Flocks of 1912–20.

Solid line represents mean winter production. Up to but not including 1917–18, the mean for the entire flock is given. From 1917–18 on, it is for the high line only. L-L′, low line. B-B′, original high line. H, mean of several high families in 1916–17. NB, mean of low-broody flock. 4128♂ and 3003♂, mean of daughters of the respective males.

Dotted line represents mean date of first egg for set of birds making winter records shown in continuous line.

Results secured.

Data on mean winter production, mean annual production, and mean age at first egg are presented for each year of the experiment. Data on broodiness have been recently published and need not be repeated here.

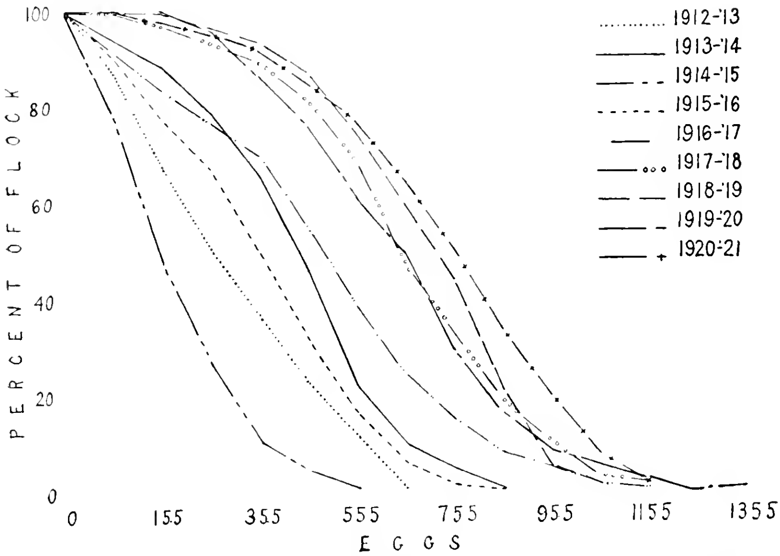


FIG. 6.—Integral Curves showing the Percentage of Each Flock having a Winter Egg Production as Great as that indicated, or Greater.

No allowance made for November in 1912. (See Table II.)

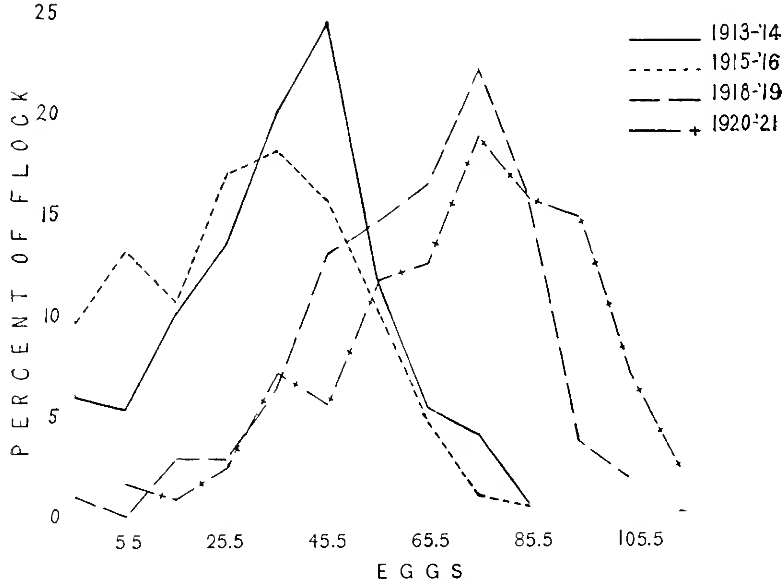


FIG. 7. — Frequency Polygons showing the Percentages of Flocks having Winter Production indicated.

1920–21 curve is for the original high line only.

Data on the initial cycle, winter pause, spring production, summer production, date of last egg and rate of production are restricted to certain years, because breeding for changes in these characteristics has necessarily been secondary. They indicate clearly such changes as have occurred. For purposes of clarity, intermediate years are omitted in certain graphs.

Changes in Mean Winter Egg Production.

Winter egg production is defined as the number of eggs laid prior to March 1 in the first laying (pullet) year. In Table II, represented graphically in Fig. 5, is given the mean winter production of the flocks from 1912 to 1920, inclusive. A high-line strain, as a definite entity, was not propagated until 1917. From 1917 on, the winter production given in the table and graph is that of the high line. A low line, L–L[1], Fig. 5, was propagated in a small way for a time, but finally lost. In 1917 a point is indicated for comparison with the high line which is the weighted production of a flock bred primarily for absence of broodiness, and in whose establishment all non-broodies available, high producers or low, were mated with three males: No. 3003; his son, No. 5470, by his sister; and his grandson, sired by No. 5470 out of an unrelated bird with a good record. The sisters of No. 3003 were noted for very low production in addition to non-broodiness. The average winter egg production of the daughters of No. 3003, as well as of the daughters of No. 4128, another low male of separate origin, is indicated for further comparison.

Graphic representation of the improvement made is shown by integral curves for each year as given in Fig. 6, while frequency polygons for winter egg production for certain years are given in Fig. 7, the statistical constants being given in Table III.

TABLE III. — *Statistical Constants for Certain of the Flocks.*

WINTER EGG PRODUCTION.

YEAR.	Number of Birds.	Mean.[1]	Standard Deviation.	Coefficient of Variation.
1913–14	171	36.70± .88	17.05± .62	46.45±2.03
1915–16	237	29.86± .76	17.40± .54	58.27±2.34
1918–19	109	63.61±1.27	19.62± .90	30.85±1.54
1919–20	124	58.56±1.45	23.93±1.02	40.87±2.02
1920–21	160	67.34±1.33	24.88± .94	36.94±1.57

ANNUAL EGG PRODUCTION.

YEAR.	Number of Birds.	Mean.[1]	Standard Deviation.	Coefficient of Variation.
1913–14	59	145.41±3.04	34.66±2.15	41.06±2.95
1915–16	211	121.21±1.87	40.20±1.32	33.17±1.20
1918–19	64	170.02±2.52	29.89±1.78	43.31±3.03
1920–21	109	200.98±2.57	39.78±1.82	33.15±1.67

[1] Means calculated from grouped data instead of ungrouped as in Table II.

TABLE III. — *Statistical Constants for Certain of the Flocks* — Concluded.

AGE AT FIRST EGG (DAYS).

YEAR.	Number of Birds.	Mean.[1]	Standard Deviation.	Coefficient of Variation.
1913 14	168	255.62±1.13	21.68± .80	48.60±2.17
1915-16	243	263.69±1.50	34.61±1.06	47.61±1.76
1918 19	141	194.58±1.38	24.23± .97	55.60±2.84
1920 21	168	200.44±1.38	26.50± .98	53.61±2.48

[1] Means calculated from grouped data instead of ungrouped as in Table II.

In Fig. 8 certain changes in winter production of selected groups are given, comprising, first, the highest record made in each season by any one individual; second, the best average record made by the daughters of any one mother, provided not less than five daughters comprised the

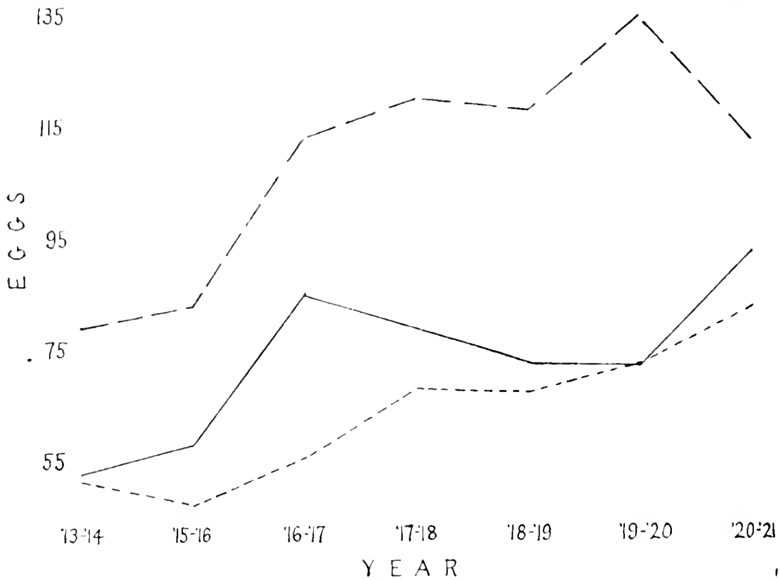


FIG. 8. — Winter Production.

Broken line, best individual; solid line, best average made by daughters of one female; dotted line, best average made by daughters of one male.

group; and third, the best average record made by the daughters of any one male for each season, provided that he had ten or more daughters.

Changes in Mean Annual Production.

Annual production is the number of eggs laid in the first laying year, beginning with the first egg and running 365 days therefrom. Barring longevity, it is probably the best index of a bird's innate laying capacity.

Reasons for this view have been presented elsewhere. In Table II and Fig. 9 are given the data showing the changes that have taken place. The statements regarding the flocks, as given for winter production, apply here also.

The integral curves for each year will be found in Fig. 10; frequency polygons are given in Fig. 11, the constants in Table III.

Changes in Daily Winter Production.

The daily flow of eggs is a matter of some importance to the commercial poultryman, because of market fluctuations in price. Daily production curves illustrating this flow show some points not brought out in curves plotted on larger time units. The labor of compiling such curves is great, however, unless birds are penned in such a way that the pen record can be used. A few such pen records have been studied and are shown in Figs. 12 and 13 (see pages 116 and 117).

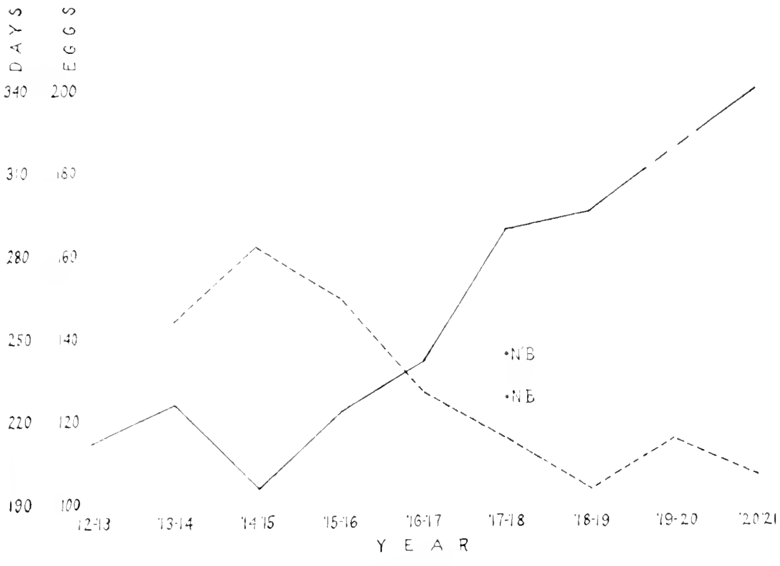


FIG. 9. — Mean Annual Production (Solid Line) and Mean Age at First Egg (Dotted Line).

NB, mean annual production, and N' B', mean age at first egg, for low-broody flock. No annual record for 1919–20. (See page 108.)

The points in all curves calling for particular attention are: the marked irregularity in number of eggs laid on consecutive days; the occurrence of waves of several sorts; the angle of slope of the curve at the beginning of production; the sharp descent from the maximum, due to the winter pause, in the curves of early hatched flocks, and the more gradual rise on recovery, with the marked rise in the curve toward the end of February. The later hatched layers do not exhibit such a sharp decline due to the winter pause. The amount is less and recovery quicker.

Changes in Age at which First Egg is laid.

Early in the history of these experiments it became evident that, on the average, those birds that laid the largest number of eggs before March 1 were those that began laying first. As the average age at which the first egg was laid was eight months, it was evident that either the pullets must be hatched early to get them mature early in the fall, or else they must grow and develop faster. Early maturity, therefore, was made the chief aim of the breeding program, with the results shown in Table II and Fig. 9. Changes in mean date of first egg, Fig. 5, vary directly with changes in mean age at first egg. Integral curves are given in Fig. 14, frequency polygons in Fig. 15 (page 119), and their constants in Table III. Note that

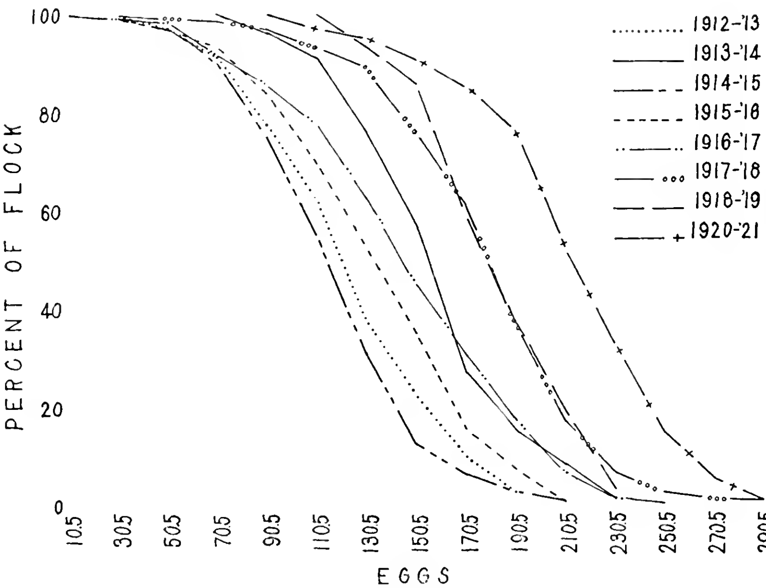


FIG. 10. — Integral Curves showing the Percentage of Each Flock having an Annual Production as Great as that indicated, or Greater.

One zero in 1917-18 is not shown. In 1912-13 no allowance is made for November production as in Table II. The curve for 1913-14 is that of the 59 birds kept through the year. (See Table II.)

apparently something more than a sifting out of an early maturing strain has occurred, as indicated by the mean and range for 1918-19, Fig. 15.

Earlier maturity uncovered, or at least was associated with, more evidence of the winter pause than appeared earlier, so that the gain in production was not as great as was anticipated. As indicated below, progress is being made in reducing the length of the pause, so that, eventually, continuous production throughout the winter is expected.

Since 1917 no attempt has been made to lower the age at first egg. The basis of selection has been the same in each year since 1917. (See

Table I and Fig. 3.) Although there is a fascinating problem involved in attempting further selection for earlier maturity, such an endeavor is not consonant with the main project.

Changes in Length of the Initial Cycle and its Complement, the Winter Pause.

In the station strain of Rhode Island Reds, many individuals produce an initial series of eggs which is followed by a rest period, the winter pause. The trait does not lend itself to ordinary statistical treatment because of its nature, which depends partly on an inherent condition of the strain, and partly on environmental conditions, particularly those

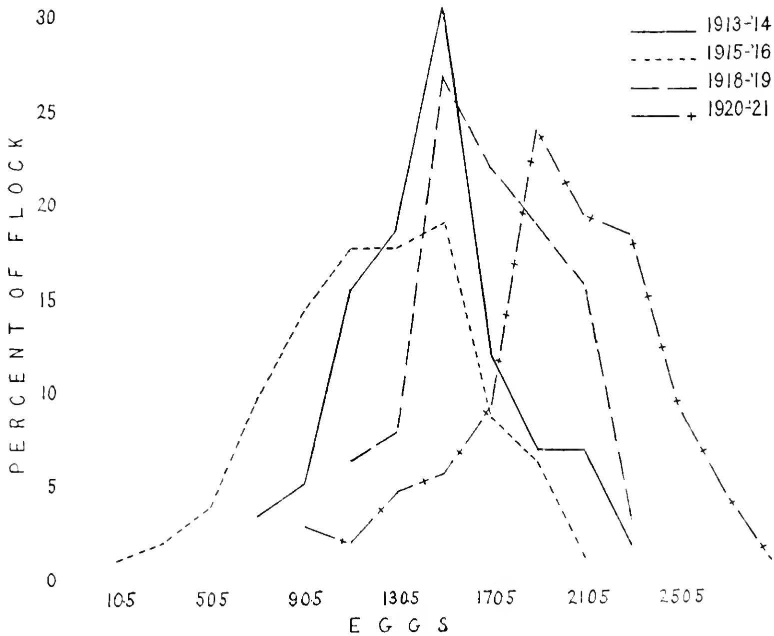


FIG. 11. — Frequency Polygons showing the Percentages of Flocks laying the Given Number of Eggs per Year.

The curve for 1913-14 is that of the 59 birds kept through the year. (See Table II.)

that determine the time of year when the birds begin to lay. Further, it is possible that more than one cycle is involved. The present discussion, therefore, is limited to a general descriptive treatment of the subject, based on experiences with flocks subsequent to those studied in an earlier paper (Goodale, 1918).

It is now clear that the earlier a pullet begins to lay in the autumn, the more likely she is to exhibit the winter pause. A few early layers, however, go through the entire winter without pausing. Roughly speaking, 90 per cent of pullets laying their first egg early in the season (September) ex-

hibit the pause, in contrast to only 30 per cent of those beginning late in the season (December). It is possible that the appearance of the pause is due to some direct effect of the season (length of days, for instance), but since there is no uniformity in the length of the egg-laying period, and since one member of a flock may begin the second laying period at the same moment another is finishing the first, it is clear that whatever influence the environment may exert is secondary, the primary cause being a change in the physiological condition of the layers, expressed in some individuals by an actual pause, in others by a slowing down in production, while in a few individuals no external effect becomes apparent. Note, as shown in Fig. 13, that a flock of late-hatched pullets were laying at a high level at the same time that their early-hatched sisters were in a slump. Clearly it is not the environment alone that is responsible for the pause. Some observations lead to the belief that environmental conditions which

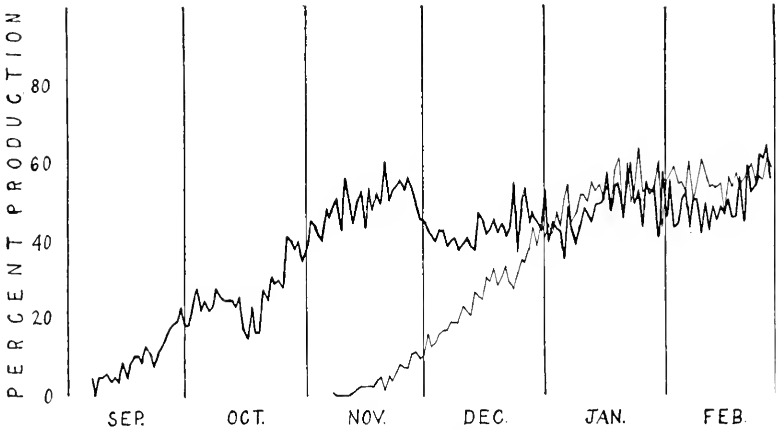


FIG. 12. — Daily Production.
Heavy line 1917–18, Pen III; light line 1913–14. (See text for details.)

at other times would not stop production may do so in this sensitive physiological state. Given an initial (winter) cycle of variable length, it is apparent that in some individuals it may extend into early spring and either overlap the spring cycle and thus fail to become apparent, or perhaps, because of a direct stimulus due to longer days, production may be kept up, and thus the winter pause is suppressed in pullets beginning to lay late in the season.

As far as possible, selection has been directed against the winter pause, and while not eliminated, there is evidence that its length has decreased, and, correspondingly, the length of the initial period increased. This is shown in Fig. 13, where a high production over a period of six weeks was maintained, which is much longer than three years previously, as seen in Fig. 12. The average number of eggs laid, prior to the pause, was 12 more in 1920 than in 1917.

Changes in Amount of Broodiness.

This phase of breeding for increased egg production has been discussed in another place (Goodale, 1920). Here it is sufficient to recall that, while some birds lay continuously throughout spring and summer without any marked slowing in rate of production, others lose much time on account of broodiness, — a loss that very clearly is *not* compensated for.

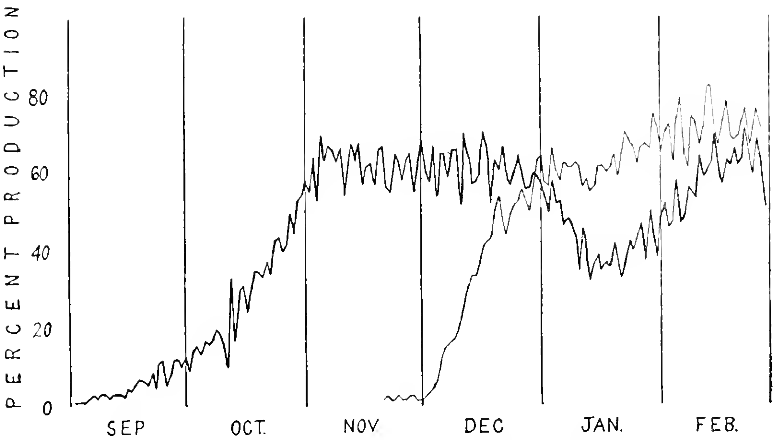


Fig. 13. — Daily Production of Two Pens of the Same Breeding, 1920–21. Heavy line, April hatched· light line, late hatched.

Note. — The records of this flock were made under quite different conditions and methods of management from those made by the other flocks. *A priori*, they appeared to be considerably sub-optimal, but the results show that they were at once correct and simple. A brief description of the conditions and methods of management follow.

The 59 females and 6 males were in a pen 22 by 11, 6 feet high at the plate and 10 at the ridgepole, made by stretching wire netting across the south side of a second-story barn floor. A windbreak of paper extended 3 feet from the floor. Roosts were at the west. The main opening was a pitch hole about 4 feet square in the south side. Additional light came from a window 2 feet square in the gable, plus some light from two openings in other parts of the loft. A little sand was put on the floor and straw used as a litter. The birds had water and open boxes of dry mash constantly before them. Oyster shell was fed on the floor. No special grit was fed. Three to 4 pounds of cracked corn were fed in the morning, and double that amount at noon. *Green* sprouted oats *ad libitum* (165 square inches) were fed at noon. Droppings accumulated on the floor back of a wire litter stop. Besides gathering the eggs and keeping straw in the nests and the litter distributed (the latter mostly done by feeding the cracked corn where it was thickest), no other attention was given. The caretaker was away during the day.

The loss due to broodiness is shown when the seasonal production of a broody race is compared with that of a non-broody race. The maximum production of a broody flock comes in March. April is nearly as high, but during May and June, corresponding to the period of progressive increase in the number of broody birds, production declines sharply to a level that either remains nearly constant for July, August and September, or in which the descent is much less marked. (See Fig. 4, 1915–16 and

1918–19.) The highline flock of 1916–17 averaged 105 eggs during the six non-broody months, November to April, while for the six broody months following, May to October, the average was only 70 eggs. Leghorns, on the other hand, continue production at a relatively high level all summer, and first decline sharply in early fall. Kirkpatrick and Card (1917) give data showing a parallelism between degrees of non-broodiness and summer production. The several races, viz., Rocks, Wyandottes, Reds and Leghorns, lay nearly the same number of eggs per bird in March and April and do not differ much in production prior to this date. But during May, June, July, August and September the Leghorns, having the smallest amount of broodiness, lay much more heavily than the other breeds, while the Reds, the most broody race, give the poorest summer production. The Rocks and Wyandottes, which are very much alike in amount of broodiness and intermediate between the Leghorns and Reds, are much alike in their summer production which is intermediate between that of the Reds and Leghorns.

A striking illustration of the loss due to broodiness in an individual bird is shown by B8316, whose egg record is given in Fig. 16. If she had not become broody, but had instead continued to lay through June, July and August at the rate of 26.4 eggs (her average for the seven months preceding), her annual production would have been 306 eggs, 27 more than her actual record of 279 eggs. (The pause in September looks much like a broody period, but she did not stick to the nest, and therefore was not put in the broody coop.)

The first experiment in breeding out broodiness was successful, but at the expense of egg production (Goodale, 1920). The experiment in breeding broodiness out of the high line and still maintaining production is not yet complete, but gives promise of success.

Changes in Date of Last Egg.

The dates of last egg and of first egg determine the length of the annual period. The two limiting dates are treated separately, because it seems probable that date of last egg results from the action of some internal mechanism the nature of which is unknown. While practically all birds are laying from the middle of March to the middle of June, after this, one by one, the birds stop laying, not to resume until next season. The majority, however, continue production till the middle of September, the mean date of last egg being near October 1 in 1914 and 1919. Cessation of production has a genetic foundation, as is indicated by the behavior of various families in this respect, some stopping early and others late. Moreover, many of the best layers show a tendency to continue production indefinitely.

The lack of evidence that the average date of cessation of production has been advanced well into the fall may be associated with lack of especial effort to secure by breeding continued production late into the fall, — an effort that did not seem worth while till after broodiness had been bred out.

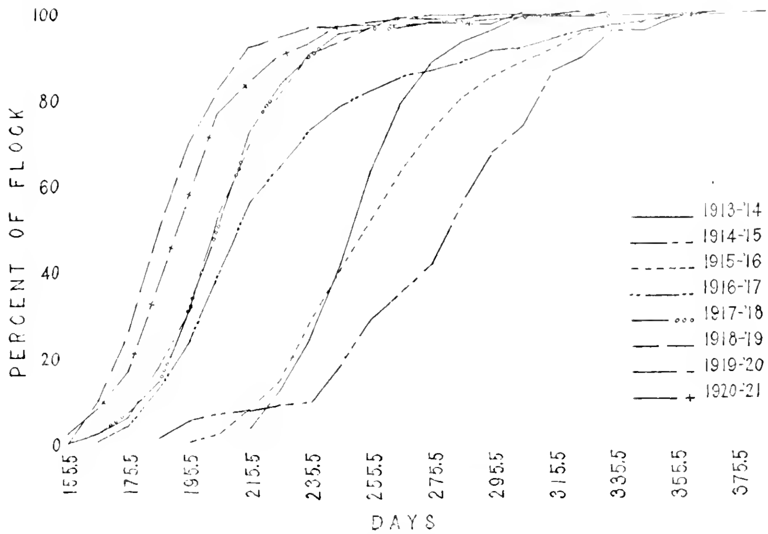


FIG. 14. — Integral Curves showing the Percentage of Each Flock beginning to lay at or before the Ages indicated.

One exceptionally old bird is omitted from 1915–16, and one from 1920–21.

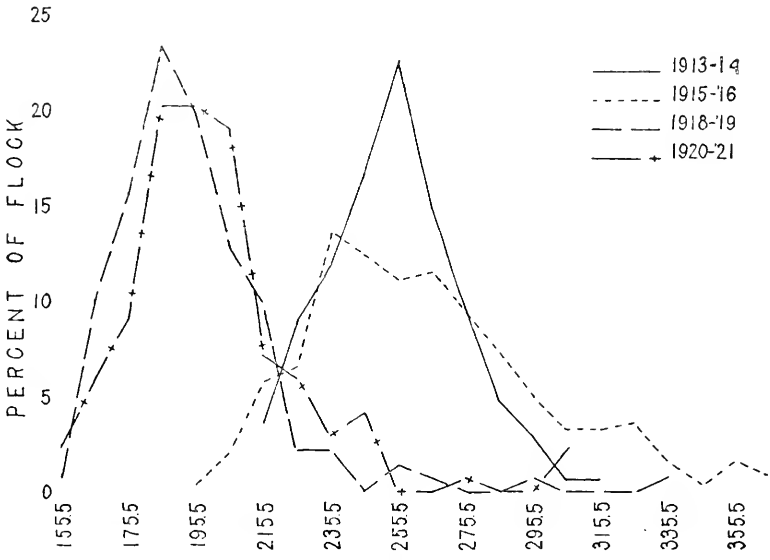


FIG. 15. — Frequency Polygons showing Percentages of Flocks beginning to lay at Ages indicated.

Changes in Rate (Intensity) of Production.

Rate or intensity of production is defined as the number of eggs laid per time unit measured in days. There are several possible time units, such as the month, the initial cycle, the inter-broody periods, the summer period and the spring period. Closely associated with this character is length of clutch, or number of days of continuous (daily) production. Units including well-defined rest periods, such as those due to broodiness or the winter pause, are specifically excluded.

While breeders have been selected, other desiderata permitting, on the basis of high monthly production during the winter, the heterogeneous condition of the flocks in respect to other characters makes comparisons unsatisfactory. The present discussion, therefore, is limited to a comparison of the highest production in any one calendar month before March 1. The use of the calendar month, instead of the highest production for a period of thirty or thirty-one days, although unsuitable in comparing individuals, is sufficiently satisfactory for comparison of flock averages. The average highest monthly production in 1913–14 was 19.28 eggs; in 1920–21 it was 21.10, showing an apparent gain of nearly 2 eggs.

Changes in Seasonal Distribution of Production.

It has been pointed out that the season at which increased production comes may be quite as important as an absolute increase. In addition to winter production, the year may be divided into spring, summer and fall, but differing from the calendar seasons.[1] Spring production includes March, April and May, chiefly because the station statistics show that, regardless of changes at other seasons, the average for these three months (Table IV) has remained nearly constant during these experiments. The period, moreover, is characterized by a sharp decline in mean monthly production from March (sometimes April) to June, due almost wholly to broodiness. A slight increase in mean production for this season has been noted with higher annual production.

[1] Other divisions might be made from the biological standpoint, but such divisions vary from flock to flock and with methods of breeding. The divisions used are approximate and somewhat arbitrary. Further, in studying seasonal distribution, the 365-day limit to a year has been disregarded.

NO. B8316 HATCHED APR. 4, 1920

DATE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	TOTAL
SEP.																																
OCT.																				1	1		1	1	1		1	1		1	1	9
NOV.	1	1	1	1	1	1		1	1	1	1	1		1	1	1	1		1	1	1	1		1	1		1	1		1		24
DEC.	1		1	1		1	1	1		1	1	1	1		1	1	1	1	1		1	1	1	1	1		1	1	1	1		24
JAN.	1	1	1	1		1		1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	27
FEB.	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1				26
MAR.	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	29
APR.	1	1		1	1	1	1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		27
MAY	1	1	1	1	1	1	1	1	1	1		1	1	1	1		1	1	1	1	1		1	1	1	1	1	1	1	1	1	28
JUN.	1	1	1	1	1	1	1	1	1		B	R	O	O	D	Y	—						1	1	1	1	1	1	1			16
JUL.		1	1	1	1	1	1	1	1	1	1	1	1		B	R	O	O	D	Y					1	1	1	1	1	1	1	19
AUG.	1	1	1	1	1	1	1	1	1	1	1	1			B	R	O	O	D	Y	—	—	—			1	1	1	1		1	17
SEP.	1	1	1	1	1	1	1	1	1	1	1	1													1	1	1	1	1	1		18
OCT.	1			1	1	1	1	1	1	1	1	1	1	1	1	1	1															15
NOV.																																

YEAR'S TOTAL 279

Fig. 16. — Egg Record of a Hen, showing the Effect of Broodiness.

TABLE IV. — *Seasonal Distribution of Production.*

YEAR.	Mean Number of Eggs for —						
	November 1 to March 1.	March 1 to May 1.	March 1 to June 1.	November 1 to May 1.	May 1 to November 1.	June 1 to October 1.	Year, November 1 to November 1.
1912-13	28.73	34.54	50.66	63.27	50.98	34.86	114.25
1913-14	36.34	33.17	47.13	69.51	54.12	40.16	123.63
1915-16	30.40	36.24	51.79	66.64	55.16	39.61	121.80
1916-17	41.39	38.15	53.60	79.54	52.91	37.46	132.45
1917-18	55.95	37.90	52.96	93.85	68.96	53.90	162.81
1918-19	56.07	38.36	55.61	94.43	67.58	50.33	162.01
1919-20	51.07	34.90	50.50	85.97	–[1]	–[1]	–[1]
1920-21	62.34	42.65	63.30	104.99	90.37	60.67	195.36

[1] Records stopped June 1. See p. 108.

Summer production includes June, July, August and September. The sharp decline previously noted is checked, and the mean monthly production declines much more gradually from month to month till October. Some years the decline is less than others (see Table V). The decline during the summer is due to the completion of the annual cycle on the part of some individuals, the first cases occurring in June, and to some slackening in rate (intensity). As shown in Table IV, there has been some increase in summer production in the high line over the earlier years. It is believed that the elimination of broodiness will be the main factor in securing further increase of production during these months.

TABLE V. — *Decrease in Mean Monthly Production from Highest Monthly Mean (March or April) to June, and from June to September.*

YEAR.	Mean Production.					
	Greatest Monthly.	June.	Difference.	June.	September.	Difference.
1913-14	M. 17.17	10.75	6.42	10.75	7.74	3.01
1915-16	M. 18.56	12.26	6.30	12.26	6.67	5.59
1916-17	M. 19.41	10.62	8.79	10.62	6.98	3.64
1917-18	M. 20.66	13.28	7.38	13.28	10.69	2.59
1918-19	A. 19.78	14.56	5.22	14.56	8.86	5.70
Average for five years .	19.12	12.29	6.82	12.29	8.19	4.11

Fall production includes October, overlapping into the following months and thus the next calendar year. It is the season of completion of the annual cycle on the part of most individuals. There is a considerable tendency for the best layers to keep producing, and, as their numbers have increased, it has been reflected in somewhat higher average production during this period.

Changes in Variability.

As shown by both the standard deviation and the coefficient of variation[1] (Table III), and by the several frequency polygons (Figs. 7, 11 and 15) for winter egg production, annual production and age at first egg, there has been no especially significant lessening of variability as a result of selection. Selection has merely moved the frequency polygon to one side without changing its general character.

Influence of Changes in Sanitary Methods.

The work was commenced on the basis of the best poultry practices available, but the sanitary measures proved wholly inadequate, and suitable methods had to be developed. There are, however, sufficient checks, indicated especially in Fig. 5, which show, with the exceptions noted in the next paragraph, that fundamentally the changes in production are due to breeding.

The low mean production of 1912–13 is due in part to late hatching. Other factors can only be guessed at. The low production of 1914–15 is probably due to improper methods of brooding plus disease and poor help.

RECOMMENDATIONS.

It is difficult, at present, to lay down a series of recommendations that can be followed by breeders, with a guarantee that they will work in every case. The following recommendations, based on experience, are intended only for the man who is prepared to go to the necessary expense, time and trouble.

A. Prerequisites.
1. Proper management, including housing, feed, sanitation.
2. Maintenance of vigor. It is true, hens of poor vigor are sometimes good layers, but good vigor as a rule is essential.
3. (*a*) Careful trapnest egg records.
   (*b*) Careful pedigree records.
4. A good understanding of both desirable and undesirable egg production characteristics in the flock to be improved.
5. Families of at least seven pullets.
6. Pullets hatched between March 25 and May 15.

---

[1] The coefficient of variation, if calculated according to the usual formula $C.V. = \frac{\sigma}{M} \times 100$, is a poor index of the real variability, since the range of the polygon does not begin at zero. It is obvious that the formula $C.V. = \frac{\sigma}{M - X} \times 100$, where X is the lower end of the range, is a better index of variability. This is the formula used for age at first egg and for annual production in Table III.

B. Method.

The flock is to be improved by degrees, taking one desirable character at a time and making sure that it is well established in the flock as a whole before concentrating on a second.

In order to be as specific as possible, the following detailed outline is given: —

First Step. — Get the flock so that the pullets will mature before 200 days of age, by choosing as breeders those that mature before that age. The males must be from hens of the same qualifications, or brothers to those families of pullets that give the greatest percentage of qualifying females.

Second Step. — Choose as breeders birds that mature right and which are not broody. This step is not necessary for Leghorns.

Third Step. — As soon as a sufficient percentage of the flock — say 50 per cent — qualifies in these two respects, make the breeders qualify in three characters. Require them to mature before 200 days of age; to be free from broodiness; and to lay 22 eggs in either November or December.

Fourth Step. — As soon as enough birds qualify, make the breeders qualify in still another point, so that the qualifications become: first egg before 200 days of age; not broody; 22 eggs in November or December; not less than 80 during the winter, and continuous production for at least twelve months. At this point, if the breeder so desires, egg size, color or other characters may be added to the qualifications required of breeders, or he may aim for still better production.

Only those females should be used a second time, at least with the same male, some of whose progeny make an advance over the parent, unless the family as a whole is better than the average of the preceding generation. On the other hand, any pairing that gives superior results may be repeated year after year, or until something better has been obtained.

It should be pointed out that the larger the flock trapnested, the more rapid should be the progress made, for with a flock of two to three thousand pullets under the trapnest, it should be possible to pick out 30 to 40 birds that when tested will give ten or fifteen breeders of proven ability. These, if properly handled, should make possible very rapid progress.

Summary.

1. A description of changes in various phases of egg production is given.

2. Both mean winter and mean annual egg production have increased.

3. The age at which the first egg is laid has been reduced.

4. Progress in eliminating both the winter pause and broodiness is shown.

5. Provisional recommendations for improving egg production by breeding are given.

Literature Cited.

Goodale, H. D. Winter Cycle of Egg Production in the Rhode Island Red Breed of the Domestic Fowl. In Jour. Agr. Research, Vol. XII, 1918.

—— —— Broodiness in Domestic Fowl. Mass. Agr. Expt. Sta. Bull. 199, 1920.

Kirkpatrick, W. F., and Card, L. E. Fifth Annual International Egg Laying Contest. Storrs (Conn.) Agr. Expt. Sta. Bull. 89, 1917.

Townsley, T. S. Report of Missouri Farm Flock Laying Contest. Mimeographic report issued by University of Missouri, November, 1920.

BULLETIN No. 212.

DEPARTMENT OF AGRICULTURE.

A THIRTY-YEAR FERTILIZER TEST.

BY SIDNEY B. HASKELL.

History of Plots.

In February of 1889 Dr. W. O. Atwater, then director of the Office of Experiment Stations of the United States Department of Agriculture, issued a call for a conference to consider and adopt if practicable a uniform method of conducting what were then called soil tests. As a result of this call a conference was held in Washington, this Station being represented by Professor Wm. P. Brooks. A method of testing the soil by means of comparative field plots was decided upon, and in Massachusetts a number of such tests were instituted. Two of these were on the Station grounds, — the South Soil Test started in 1889 and the North Soil Test in 1890. Nine similar tests were laid out in other parts of the State. The object was "to find out the particular fertilizer requirements of the soils of different localities;" and in the letter sent out arranging for the co-operative tests, the statement was made that "the best soil for the purpose is one which represents best the average conditions in your county, which is level or of uniform moderate slope, of uniform and low fertility, and now in grass."

Up to and including 1917 these soil tests were under the supervision of Dr. William P. Brooks, formerly agriculturist and later director and agriculturist of the Experiment Station. Progress reports under the authorship of Dr. Brooks were made in Bulletins Nos. 9, 14, 18 and 58 of the Hatch Experiment Station, and likewise in the annual reports of that Station and its successor, the Massachusetts Agricultural Experiment Station. Records from these tests, with analysis and discussion, were also published in "Das Nährstoffbedürfnis Verschiedener in Fruchtfolge auf demselben Felde Angebauter Pflanzen nach Versuchen in Massachusetts, Nordamerika," presented by Dr. Brooks at the University of Halle, Germany, as a doctorate dissertation.

The greatest service of these field tests to date has probably been the establishment of the fact that individual crops vary widely in their plant food requirements, and that fertility practice may be affected more by

the kind of crop than by the type of soil on which it is grown. Dr. Brooks presented this idea in his summarization of these experiments published in Bulletin No. 58 above cited, and was one of the first, if not the first, of the fertility workers of the country to observe this fact. Results secured during the score of years which has elapsed since the observation was first made have confirmed the conclusion in abundant measure.

The South Soil Test.

This test is on a soil classified in the soil survey of the Connecticut Valley as a Merrimac coarse sandy loam. The field is practically level, and had been in grass without manure for five years previous to the laying out of the test. Earlier still, for an unknown number of years, it had been in pasture.

Cropping System.

The original plan was apparently that of a five-year rotation, consisting of two years of corn, then a grain crop, followed by two years of grass and clover. This plan, however, was not followed consistently, although, in the thirty years of which we have full record, thirteen corn crops were grown. A complete list of crops as grown year by year is contained in Table I of the Appendix.

Fertilizer Treatment.

The fertilizer treatment is shown in the following schedule: —

Plot.	Fertilizer.	Pounds per Acre.
1	Nitrate of soda	160
2	Dissolved boneblack	320
3	Nothing.	
4	Muriate of potash	160
5	Lime	800
6	Nothing.	
7	Manure	30,000
8	Nitrate of soda Dissolved boneblack	160 320
9	Nothing.	
10	Nitrate of soda Muriate of potash	160 160
11	Dissolved boneblack Muriate of potash	320 160
12	Nothing.	
13	Plaster	800
14	Nitrate of soda Dissolved boneblack Muriate of potash	160 320 160

The plots were 18 by 121 feet in size, or exactly one-twentieth of an acre. A strip 3 feet wide between plots was cultivated as though a part of the adjacent plots, but yields on these strips were never recorded.

Lime History.

Lime was applied in the following amounts: —

Year.		Pounds per Acre.
1899.	Slaked lime	2,000
1904.	Slaked lime, about	3,000
1907.	Agricultural lime, about	1,000
1909.	Agricultural lime	2,000
1916.	Ground limestone	4,000

Precipitation and Frost Records.

Tables II and III in the Appendix show the observations on temperature, frost and precipitation as taken by the Department of Meteorology of the Experiment Station for the years from 1889 to 1921, inclusive.

During this thirty-three-year period there have occurred certain fairly definite weather cycles. For a period of eight years, 1897 to 1904, inclusive, the annual rainfall was consecutively above the mean for the period. From 1907 to 1914, inclusive, with the exception of a single year, the annual precipitation was below the mean of the period, and averaged 10 inches annually below that of the preceding period. From 1907 to 1913 the rainfall of the growing season, April to August, inclusive, averaged 14.7 inches; while for the succeeding seven years the average for the same period was 20.3 inches. There were also in the whole period wide extremes in total precipitation, the least being 10.82 inches for the growing period in 1894, and the highest 32.25 inches in 1892. The growing season, or the time between the last killing frost of the spring and the first killing frost of autumn, varied from 99 days in 1894 to 164 days in 1920. With such wide variations in weather conditions, especially as regards the dominant influence of precipitation, temperature and length of season, it is not to be expected that results from fertilizer use would in all cases be as expected, or show records always consistent one with the other.

Yields.

A complete statement of yields is given in Table I of the Appendix. Corn was grown more often than any other single crop, there having been a total of thirteen corn crops. For two years preceding the eleventh crop, however, the land was practically fallow; while the twelfth and thirteenth crops followed partial or total crop failures. The best picture of results, therefore, may be obtained by considering the corn crop as the common denominator of all the crops, and dividing the corn yields into three periods, including the first five crops in the first, the second five in the second, and the last three somewhat abnormal crops in the third, as shown in Table 1: —

TABLE 1. — *The Corn Crops.*

Grain (Average Yields per Acre, Bushels).

Plot.	Treatment.	First Period.	Second Period.	Third Period.
1	Nitrate of soda	26.73	6.05	26.55
2	Dissolved boneblack	23.96	4.52	13.03
3	Nothing	20.74	4.31	10.97
4	Muriate of potash	44.61	31.83	44.79
5	Lime	23.71	2.81	9.26
6	Nothing	20.79	5.27	11.08
7	Manure	63.11	57.20	56.13
8	Nitrate of soda Dissolved boneblack	32.33	9.84	–[1]
9	Nothing	25.37	5.53	–[1]
10	Nitrate of soda Muriate of potash	42.07	35.38	43.85
11	Dissolved boneblack Muriate of potash	54.90	39.33	44.53
12	Nothing	23.10	7.50	20.43
13	Plaster	27.09	9.14	14.54
14	Nitrate of soda Dissolved boneblack Muriate of potash	62.46	41.89	38.52

[1] These plots were discontinued in 1911.

These results are presented in graphic form in Fig. 1, arranged to show the total yields of grain and stover, and likewise the comparative yields in the two five-year periods. It will be noted that the yield of grain decreased very materially and significantly in the second five-year period. In all of those plots to which potash treatment was applied, the yield of stover did not decrease in like measure. On the other hand, where potash was not applied, the decrease in the yield of stover was somewhat similar in its significance to the decrease in grain. In all cases, the number of pounds of stover produced per bushel of grain was larger in the second period than in the first, and very materially so in the no-potash treatments.

The First Ten Corn Crops.

The Check Plots. — The significance of the results and their interpretations may best be judged on the basis of the yields on the check plots. There were four such plots, numbered respectively, 3, 6, 9 and 12. The following table shows the yields of corn divided into two five-year periods. Under the system of farming followed, the yielding power of the untreated soil was very low. The acre yields in the second period were practically zero. The check plots were, however, fairly uniform in production.

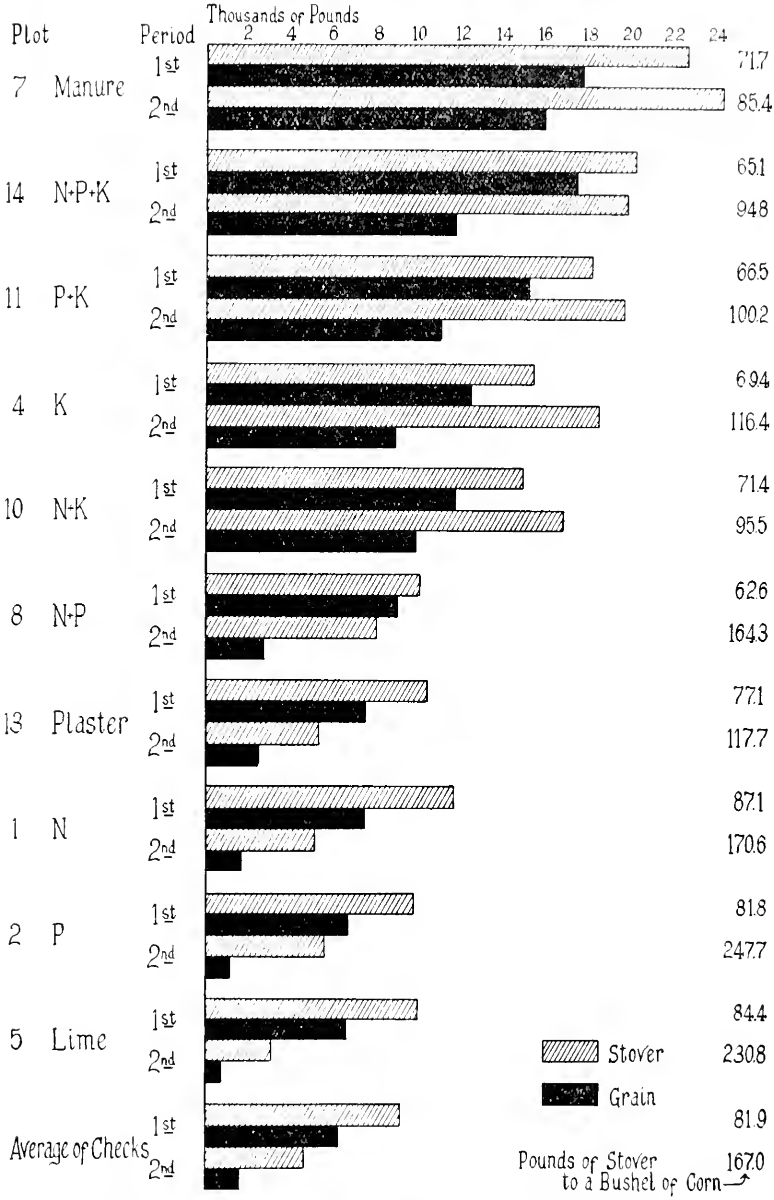


FIG. 51. — South Soil Test. Total yields per acre. Ten corn crops.

TABLE 2. — *The Check Plots.*

Plot.	Corn (Bushels per Acre).		
	First Period.	Second Period.	Decrease.
3	20.74	4.31	16.43
6	20.79	5.27	15.52
9	25.37	5.53	19.84
12	23.10	7.50	15.60

The Effect of Potash. — The most marked and most striking result of the test, especially as indicated by the corn crop, was the great response to potash. The following table shows the average yields of corn for the two periods under discussion for those treatments which include this plant food: —

TABLE 3. — *The Treatments containing Potash.*

Plot.	Treatment.	Corn (Bushels per Acre).		
		First Period.	Second Period.	Decrease.
4	Muriate of potash	44.61	31.83	12.78
7	Manure	63.11	57.20	5.91
10	Nitrate of soda Muriate of potash	42.07	35.38	6.69
11	Dissolved boneblack Muriate of potash	54.90	39.33	15.57
14	Nitrate of soda Dissolved boneblack Muriate of potash	62.46	41.89	20.57

Potash alone was effective, although the difference between the first period and the second period is very large. This treatment outyielded the potash and nitrogen treatment in the first period, but results were reversed in the second.

The use of a mineral plant-food ration consisting of phosphoric acid and potash gave marked results. Here again, however, the decrease in yield between the two periods was fully as great as, in fact somewhat larger than, the decrease on either the potash or potash and nitrogen plots. On the complete fertilizer, however, the decrease was even greater; for whereas this treatment was definitely superior in yield during the first period, it was very little better than the phosphoric acid and potash treatment in the second.

There are two explanations for this apparent decrease in yielding power in the two periods under discussion. The weather conditions may not

have been the same for the two series of corn years; and the destructive system of farming followed may have seriously affected the ability of the soil to produce crops on fertilizers alone, as compared to its ability to produce crops on barnyard manure.

With reference to the first possibility, Table 6, page 136, presents data for moisture and temperature during all of the years in question. An attempt is made to epitomize these records in a single sentence descriptive of the growing conditions for the years in question. Bringing these together, the following picture is obtained of the comparative growing conditions in the two periods: —

First Period.		*Second Period.*	
1889.	Warm and moist in the early season.	1902.	Cool with abundant moisture.
1890.	Normal.	1903.	Drought in May; very cold and wet in June; very cold in August.
1894.	Warm and generally dry following a dry winter.	1904.	Wet spring; cool.
1898.	Good growing season.	1907.	Cold and dry following a dry winter.
1899.	Slight moisture deficiency.	1910.	Drought.

It is evident that the weather conditions in the last period were less favorable than in the first period.

In interpreting the significance of the above facts, thought must be given to the farming system followed. At the very beginning the stage was apparently set, although unconsciously, for a crop increase from the use of fertilizer potash. Grass, a heavy potash feeder, had been occupying the land for a number of years, but without return to the soil of either manure or fertilizer. As the years passed, this initial condition was accentuated through the removal from the soil of successive crops of corn and of grass and clover. Had these crops been fed on the farm, as in practical agriculture they must have been, there would have been potash return to the soil by natural means and less need for the use of commercial potash.

The Destructive Treatments. — A number of treatments were definitely destructive, *i.e.*, yields decreased definitely and significantly from one period to another, and reached a point at which profitable farming would have been absolutely impossible. Nitrate of soda alone, acid phosphate alone, lime alone, nitrate of soda and acid phosphate, and land plaster come in this list. The average yields for the first and second periods for plots treated with these materials were as follows: —

TABLE 4. — *The Destructive Treatments.*

Plot.	Treatment.	Corn (Bushels per Acre).		
		First Period.	Second Period.	Decrease.
1	Nitrate of soda	26.73	6.05	20.68
2	Dissolved boneblack	23.96	4.52	19.44
5	Lime	23.71	2.81	20.90
8	Nitrate of soda Dissolved boneblack	32.33	9.84	22.49
13	Plaster	27.09	9.14	17.95

Since the farming system followed was one which logically and on many soils inevitably results in need of complete fertilizer applied in large quantities, it is not astonishing that the one-sided treatments should give such poor results.

It will be noted that the above-mentioned destructive treatments are those which contain no potash, which fact is of importance in connection with the lime history of the field. Commencing in 1899, lime was applied at frequent intervals, and in generous quantity. It has sometimes been claimed that such use of lime makes soil potash available. Did it have such an effect, it would be expected that the yields on the nitrate of soda, the dissolved boneblack (acid phosphate) and the nitrate and boneblack plots would approximate those secured on equivalent treatments with potash added. This expectation has not been realized. There is no indication in the data at hand that lime has had any measurable or significant effect in increasing the availability of soil potash.

Manure versus Fertilizer. — Table 5 shows the comparative corn yields year by year, with averages for the two periods in question, of Plot 7, receiving manure, and Plot 14, receiving complete fertilizer.

TABLE 5. — *Comparison of Manure and Complete Fertilizer.*

First Period.			Second Period.		
Year.	Corn (bushels per acre).		Year.	Corn (bushels per acre).	
	Plot 7, Manure.	Plot 14, Complete Fertilizer.		Plot 7, Manure.	Plot 14, Complete Fertilizer.
1889	57.50	61.50	1902	68.70	56.20
1890	59.75	71.00	1903	37.39	25.56
1894	54.70	51.00	1904	50.00	47.78
1898	67.70	55.90	1907	72.50	38.31
1899	75.90	72.90	1910	57.43	41.57
Average	63.11	62.46	Average	57.20	41.89

For the first five crops the two treatments gave practically the same results. For the last five crops, yields were maintained fairly well by the manure treatment, and not at all well on the fertilizer treatment. This difference in plot behavior may be explained, in part, either by the fact that manure contained organic matter while the fertilizer used did not, or by the difference in plant food. The amounts of plant food applied per acre in the two contrasted treatments are as follows: —

	Pounds per Acre (Average per Year).	
	Applied in Manure.	Applied in Fertilizer.
Nitrogen	108	24
Phosphoric acid	118	51
Potash	169	80

The amount of manure used is larger than could have been produced had all crops grown been fed to animals and all of the manure produced carefully saved and returned to the land. For this reason the fact brought out in the foregoing table has no great significance in its bearing on actual practice.

Response of Corn to Fertilizer Nitrogen. — There was wide variation in the degree of response of the crop to the use of fertilizer nitrogen. In two cases there was apparently a significant decrease in crop produced by such use, — a result which, while unusual, is by no means impossible. Owing to its favorable effect on nitrification, corn seldom shows marked response to the use of this plant food except under those conditions where the soil supply of organic nitrogen is very limited. Less response would therefore be expected on the corn crops following legumes or grown on sod than on the corn crops following non-legumes or grown on stubble, while the greatest increase would be expected from those corn crops which are three years from a legume.

The following tabulation was made to see if this expectancy be supported by facts. Owing to the comparatively small variation in checks, the yields on the phosphoric acid and potash plot are compared directly with those on the complete fertilizer plots. The yields on the manure plots are included, as significant of results secured where there was a sufficiency of plant food and organic matter in the soil. Since moisture and temperature conditions influence nitrification, the departure from normal of both precipitation and mean hourly temperature is tabulated alongside the yield records.

TABLE 6. — *Relationship between Increase from Fertilizer Nitrogen, Place in Rotation and Weather Conditions.*

CORN, YIELDS PER ACRE, SOUTH SOIL TEST.

I. *Following Legume or "Old Sod."*

[The first row of figures under the date line is bushels of corn per acre; the second row, pounds of stover per acre.]

Precipitation (Inches). Above Normal.		Precipitation (Inches). Below Normal.	Manure.	Phosphoric Acid and Potash.	Nitrogen, Phosphoric Acid and Potash.	Mean Hourly Temperature (Degrees Fahrenheit). Above Normal.		Mean Hourly Temperature (Degrees Fahrenheit). Below Normal.
			1889.					
	April	−0.84	57.50	58.00	61.50	+3.2	April	
+1.03	May		4,200	3,960	4,180	+4.0	May	
+1.63	June		Warm and moist in early season.			+2.0	June	
+6.11	July						July	−1.1
	August	−1.53					August	−2.5
			1894.					
	April	−1.42	54.7	49.5	51.0	+1.8	April	
+0.32	May		3,760	3,820	3,780	+1.3	May	
	June	−0.25	Warm and generally dry following a dry winter.			+3.7	June	
	July	−2.86				+2.9	July	
	August	−3.94				+1.3	August	
			1902.					
+0.05	April		68.7	55.9	56.2	+1.2	April	
	May	−1.36	6,220	4,640	4,540		May	−0.4
+1.16	June		Cool and abundant moisture.				June	−2.2
+0.25	July						July	−2.8
+0.40	August						August	−1.9
			1907.					
	April	−1.28	72.50	30.13	38.31		April	−4.6
+0.34	May		6,900	6,500	5,500		May	−5.6
	June	−1.02	Cold and dry following a dry winter.				June	−1.8
	July	−0.54					July	−0.6
	August	−2.81					August	−1.9
			1913.					
+0.04	April		66.8	49.7	44.4	+1.5	April	
+1.26	May		5,140	4,040	3,840		May	−1.8
	June	−2.48	Dry from June on.			+0.7	June	
	July	−2.82				+0.8	July	
	August	−1.99				+1.5	August	
			1915.					
+0.73	April		60.79	37.58	35.15	+3.8	April	
	May	−2.48	3,520	3,250	3,400		May	−3.3
	June	−0.38	Cool, with flood conditions in late season.				June	−1.5
+4.72	July						July	−1.7
+4.03	August						August	−2.0
			1917.					
	April	−1.43	40.8	46.3	36.0		April	−3.2
+0.45	May		5,200	3,300	5,400		May	−8.1
+1.89	June		Very cool in early season.				June	−0.4
	July	−1.05				+1.1	July	
+2.81	August					+2.9	August	

TABLE 6. — *Relationship between Increase from Fertilizer Nitrogen, Place in Rotation, and Weather Conditions* — Continued.

CORN, YIELDS PER ACRE, SOUTH SOIL TEST — *Concluded.*

II. *Second Year after Legume or Sod.*

Precipitation (Inches). Above Normal.		Precipitation (Inches). Below Normal.	Manure.	Phosphoric Acid and Potash.	Nitrogen, Phosphoric Acid and Potash.	Mean Hourly Temperature (Degrees Fahrenheit). Above Normal.		Mean Hourly Temperature (Degrees Fahrenheit). Below Normal.
			1890.					
	April	—1.53	59 75	65.90	71 00	+0.4	April	
+1.71	May		5,520	4,880	5,320		May	—0 3
	June	—1.85	"Normal."				June	—0 4
+1.22	July						July	—0.8
+0.63	August						August	—0.8
			1898.					
+0 47	April		67.7	41.2	55.9		April	—3 1
+1.93	May		3,800	2,440	2,600		May	—1.8
+0 31	June		Good growing conditions.			+0 3	June	
+0.32	July					+0.3	July	
+2.60	August					+1.7	August	
			1903.					
	April	—0.96	37.39	20 39	25.56	+0.8	April	
	May	—3.20	3,600	2,320	3,040	+1.8	May	
+4.41	June		*Drought in May;* very cold and wet in June; very cold in August.				June	—6.1
+0.23	July						July	—1 7
+0.67	August						August	—6.0
			1910.					
	April	—0 19	57.43	37.14	41.57	+4.5	April	
	May	—1 01	3,700	2,300	3,080		May	—1.3
	June	—0.73	Drought.				June	—1.9
	July	—2.51				+1.5	July	
	August	—0.22					August	—0.9
			III. *Third Year after Legume or Sod.*					
			1899.					
	April	—1 47	75.9	59 9	72.9		April	0
	May	—2.40	5,350	3,160	4,450		May	—1.7
+0.75	June		Slight moisture deficiency.			+1.7	June	
+0.48	July						July	—0.5
	August	—2.25					August	0
			1904.					
+2 47	April		50 00	53 11	47.78		April	—3.6
+0 87	May		4,000	3,940	3,700	+2.7	May	
+1.97	June		Wet spring; cool.				June	—0 7
	July	—1.79					July	—0 8
	August	—0.16					August	—1.6

TABLE 6. — *Relationship between Increase from Fertilizer Nitrogen, Place in Rotation, and Weather Conditions* — Concluded.

CORN, YIELDS PER ACRE, NORTH SOIL TEST.

I. *Following Legume or Sod.*

PRECIPITATION (INCHES).			Manure.	Phosphoric Acid and Potash.	Nitrogen, Phosphoric Acid and Potash.	MEAN HOURLY TEMPERATURE (DEGREES FAHRENHEIT).		
Above Normal.		Below Normal.				Above Normal.		Below Normal.
				1890.				
				Whole Plot.				
	April	—1.53		74 0	74 9	+0.4	April	
+1.71	May			5,740	5,820		May	—0.3
	June	—1.85		"Normal."			June	—0.4
+1.22	July						July	—0.8
+0.63	August						August	—0.8
				1905.				
				Limed.				
	April	—0.70		34.24	43 06		April	—0 5
	May	—2.40		3,400	4,840		May	—0.5
	June	—0 52		Cool and very dry.			June	—1.3
	July	—1.78				+0.5	July	
+2.22	August						August	—2.2
				Unlimed.				
				11 29	36.24			
				4,520	5,840			
				1916.				
				Limed.				
+0.43	April			48.1	41 2		April	—2.2
	May	—0.47		4,000	4,200		May	—1.5
+1.96	June						June	—4.6
+2.44	July					+1.0	July	
	August	—1.76				+1.5	August	
				Unlimed.				
				30 3	38.3			
				2,500	4,200			

In the year following a legume there has been no consistent response of the crop to the use of fertilizer nitrogen, and this almost without regard to the condition of the weather. The second year after a legume, however, there has been such response, — in one case in a marked degree. In the two cases where corn was planted three years after the legume, one showed an apparent increase rather significant in size, the other an apparent decrease.

For comparison, the results of the three corn crops grown on the North Soil Test are presented. All of these were grown after sod or legume. On the limed section or on the undivided plot, nitrogen brought a crop increase in one case out of three. On the unlimed section, in the two years of record, there was a definite increase. This result may trace back to the poor growth of the clover on the unlimed land.

The Last Three Corn Crops.

Cultural methods from 1909 on departed widely from the normal. In 1908 a catch crop of crimson clover was turned under as a green manure. In 1909 a partial crop of buckwheat was turned under. In 1911 there was

a cultivated fallow, and in 1912 something which in its effect was practically a fallow. The 1913 corn crop therefore had the benefit of two years of soil idleness. In 1914 a crop of soy beans failed to mature, and hence presumably left more of value in the stubble than would have been the case had the crop ripened its seed. In 1916 sweet clover was sown, but the crop appeared to be mostly weeds. This was cut and removed from the soil but not weighed. The corn crops of 1913, 1915 and 1917 therefore are not comparable with the earlier crops, although they may indicate the fertility tendencies as brought about by this abnormal treatment.

The Hay Crops.

There were six crops of grass and clover. One of the most marked results in the whole history of the experiment was the character of the vegetation produced by differential fertilizer treatment on uniform seeding. Clovers failed to grow where potash was not applied. The effect of this is shown primarily in the rowen crop, which consisted largely of clover. The number of hay crops was, however, too small and the crop too responsive to varying weather conditions to admit of any very satisfactory interpretation of the data. The graphic presentation (Fig. 2) represents the total yields for the six crops.

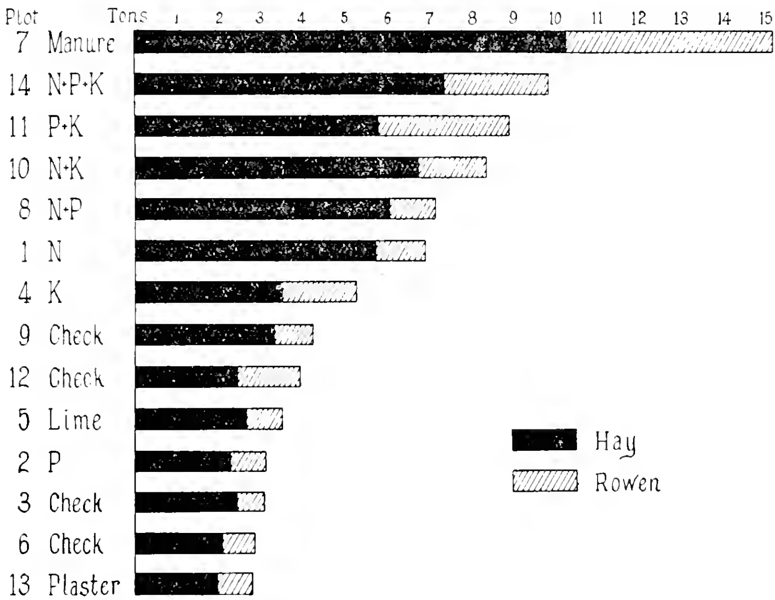


FIG. 2. — South Soil Test. Total yields per acre. Six hay crops.

Financial Interpretation.

No satisfactory financial interpretation of the results of the experiment is possible. Fertilizers were applied according to a set schedule, without reference to the value of the crop or to its ability to make payment through increased acre value for the plant food applied. Neither was there any attempt to estimate the necessity of one plant food or another as indicated by the previous history of the plots, and response of the crops grown to varying fertility treatments.

The North Soil Test.

History.

This field was started in 1890. Previously it had been pasture, without definite manure application, for a number of years. The plots are located about 150 yards from the South Soil Test, and are on soil of the same formation, although with a more definite slope toward the west. Fig. 3 shows the shape and arrangement of plots as compared with the South Soil Test.

Fertilizer Treatment.

The fertilizer treatment was the same in principle as that on the South Soil Test, except that the plots were differently laid out and hence bore different numbers. The schedule follows: —

Plot.	Treatment.	Pounds per Acre.
1	No fertilizer.	
2	Nitrate of soda	160
3	Dissolved boneblack	320
4	No fertilizer.	
5	Muriate of potash	160
6	Nitrate of soda Dissolved boneblack	160 320
7	Nitrate of soda Muriate of potash	160 160
8	No fertilizer.	
9	Dissolved boneblack Muriate of potash	320 160
10	Nitrate of soda Dissolved boneblack Muriate of potash	160 320 160
11	Plaster	800[1]
12	No fertilizer.	

[1] 1892–95, 160 pounds per acre; 1896, increased to 400 pounds per acre; 1902, increased to 800 pounds per acre.

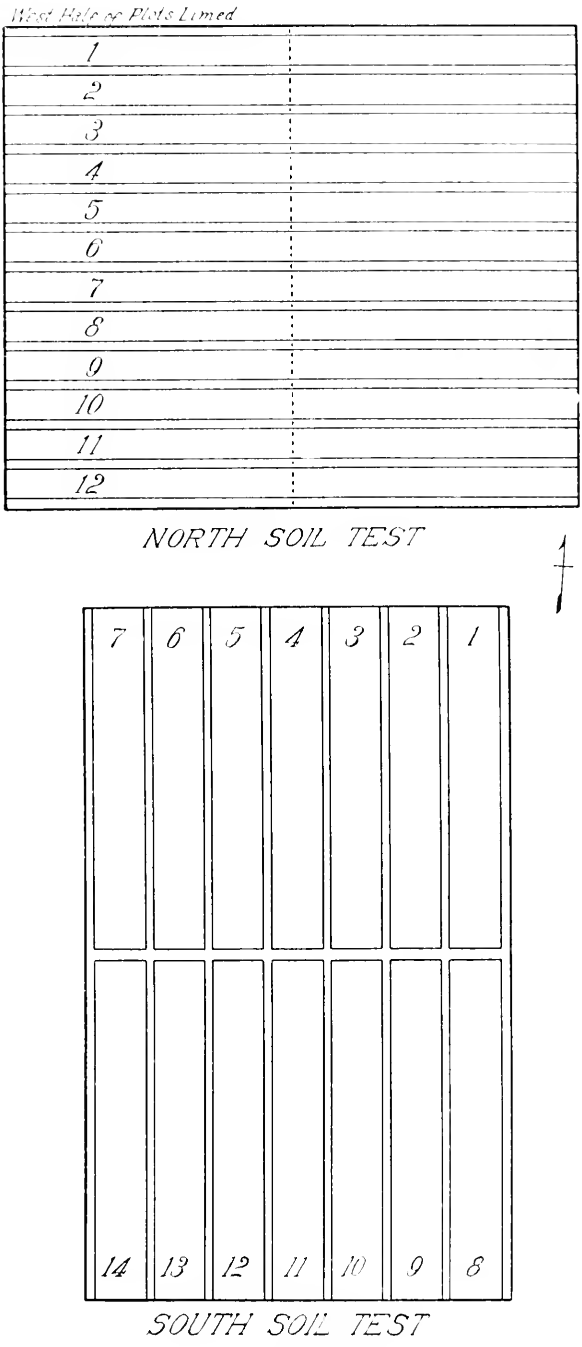


FIG. 3. — Plan of the plots.

In 1897 and 1902 for potatoes, in 1898, 1899, 1900 and 1901 for onions, and in 1903 and 1904 for grass and clover, the fertilizer applications were doubled. In 1899 lime was applied to the west half of the field, and was repeated in 1904, 1907 and 1916, a total of 4½ tons per acre of lime in one form or another being applied over a period of eighteen years.

Table IV of the Appendix gives the record of yields over the period of the experiment.

Variation in Checks.

The check plots were very variable. The yields of grass and clover on the limed and unlimed halves of the field illustrate this fact.

TABLE 7. — *Grass and Clover Yields on Check Plots (Yields per Acre, Pounds).*

Year.	Unlimed.				Limed.			
	Plot 1.	Plot 4.	Plot 8.	Plot 12.	Plot 1.	Plot 4.	Plot 8.	Plot 12.
1903	360	**550**	450	420	**1,150**	1,010	570	1,140
1904	**1,200**	590	600	650	880	690	1,440	**1,520**
1908	**1,340**	780	480	440	2,160	1,560	1,640	**2,220**
1909	**1,280**	1,180	1,150	720	**1,570**	1,520	1,560	1,520
1914	**1,600**	1,240	820	600	1,840	2,030	2,920	**3,060**
1915	920	**1,020**	520	480	1,480	2,220	2,320	**2,940**

The highest yielding plots in each year are bold-faced type.

Plot 1 on the limed and unlimed portions of the field is seemingly superior, at least in its ability to grow grass and clover, to Plots 4 and 8. Plot 12, unlimed, is the poorest of the checks, while on the limed portion of the field it is superior to Plot 1. Owing to this variation in different parts of the field, the data presented in Table IV of the Appendix do not permit of clear-cut numerical discussion. They serve to indicate tendencies rather than to furnish statistical proof. It is probable, also, that the natural variation in the checks has been exaggerated somewhat by the fact that there has been cross washing on this field, the soil working in a more or less diagonal direction from the unlimed portion of Plot 12 to the limed half of Plot 1.

Effect of Lime and of Fertilizer Applications.

Even though the uniformity of conditions is not as great as could be desired, the results from the use of many of the plant food and lime combinations are so striking as to be beyond the range of probable experimental error. Table 8 has accordingly been prepared, showing the comparisons for a number of the more important crops grown. From this table the following facts are developed: —

1. The effect of lime is very marked, but crop increase from its use is less when it is added to phosphoric acid alone, or to phosphoric acid and nitrogen, than when added to any other treatment. In general, the phosphoric acid and nitrogen treatment on the unlimed portion of the field leads all except the complete fertilizer. On the limed portion, however, complete fertilizer, phosphoric acid and potash, nitrogen and potash, and, occasionally, potash alone are superior.

2. The gain from applying lime in addition to a ration of potash alone is very much greater than from applying it in addition to phosphoric acid.

3. Potash has not given as marked results as on the South Soil Test.

4. The use of potash, phosphoric acid and lime has maintained yields at a comparatively high level, despite the infrequency with which clovers have been grown.

5. Nitrogen, used in addition to phosphoric acid and potash, has given fairly large increases in crop.

Effect of Lime on the Availability of Soil Potash.

On the limed half of this field there are three comparisons — namely, nitrogen with and without potash, phosphoric acid with and without potash, nitrogen and phosphoric acid with and without potash — where the effect of lime in increasing the availability of soil potash should be apparent. Table 9 shows the crop yields secured and presents the estimated gain from the use of potash in each case.

TABLE 8. — *The Interrelation of Lime and Fertilizer (Yields per Acre).*

Crop.	Average of Checks (Plots 1, 4, 8, 12).			Nitrogen (Plot 2).			Phosphoric Acid (Plot 3).			Potash (Plot 5).		
	Limed.	Unlimed.	Apparent Gain from Liming.	Limed.	Unlimed.	Apparent Gain from Liming.	Limed.	Unlimed.	Apparent Gain from Liming.	Limed.	Unlimed.	Apparent Gain from Liming.
Grass and clover:												
1903	968	445	-	3,140	1,520	-	1,560	950	-	950	660	-
1904	1,133	760	-	1,690	2,020	-	800	1,060	-	2,700	670	-
1908	1,895	760	-	3,880	3,280	-	1,600	940	-	2,380	860	-
1909	1,543	1,083	-	1,780	1,980	-	1,420	1,260	-	3,640	1,050	-
1914	2,463	1,065	-	2,870	2,020	-	1,680	1,490	-	5,540	1,280	-
1915	2,240	735	-	1,580	1,440	-	1,380	1,180	-	6,750	1,580	-
Average	1,707	808	+899	2,490	2,013	+447	1,407	1,147	+260	3,660	1,017	+2,643
Beans (green weight), 1918	1,005	1,680	—675	960	1,240	—280	800	960	—160	3,840	2,320	+1,520
Cabbage, 1917	18,410	1,365	+17,045	23,240	3,080	+20,160	9,220	9,800	—580	22,680	1,580	+21,100
Corn, grain (bushels):												
1905	13.7	8.7	-	9.1	13.9	-	5.9	7.8	-	18.4	5.7	-
1916	27.1	20.2	-	19.7	34.5	-	21.7	35.1	-	36.9	25.9	-
Average	20.4	14.5	+5.9	14.4	24.2	—9.8	13.8	21.4	—7.6	27.8	15.8	+12.0
Corn, stover:												
1905	2,810	2,800	-	3,960	480	-	2,640	3,400	-	4,400	4,010	-
1916	1,800	1,700	-	1,600	2,200	-	1,600	3,000	-	2,600	3,000	-
Average	2,305	2,250	+55	2,780	1,340	+1,440	2,120	3,200	—1,080	3,500	3,520	—20
Soy beans (bushels):												
1906	7.6	10.5	-	3.5	4.5	-	4.0	5.5	-	12.4	8.3	-
1910	17.7	12.1	-	19.3	14.8	-	13.8	11.4	-	24.8	9.0	-
1911	6.3	10.6	-	2.1	4.7	-	.9	4.7	-	20.3	14.5	-
Average	10.5	11.1	—.6	8.3	8.0	+.3	6.2	7.2	—1.0	19.2	10.6	+8.6

Soy beans, straw:												
1906	503	660	-	490	410	-	400	380	-	720	520	-
1910	3,235	1,625	-	3,180	3,140	-	2,800	2,680	-	1,560	1,680	-
1911	2,033	1,818	-	1,480	1,450	-	950	1,530	-	2,820	2,160	-
Average	1,924	1,378	+546	1,817	1,677	+140	1,383	1,530	—147	1,700	1,453	+247
Onions (bushels):												
1899	19.5[1]	3.7[1]	-	91.4	18.7	-	12.3	6.5	-	161.7[1]	3.1	-
1900	95.9	35.2	-	155.0	50.0	-	37.7	17.3	-	383.5	37.7	-
Average	57.7	19.5	+38.2	123.2	31.4	+88.8	25.0	11.9	+13.1	272.6	20.4	+252.2
Potatoes (bushels), 1902	48.7	54.1	—5.4	47.6	50.7	—3.1	48.0	59.3	—11.3	81.7	73.3	+8.4
Rye, grain (bushels):												
1913	33.9	24.1	-	36.4	30.7	-	28.9	29.6	-	35.3	28.9	-
1921	13.1	8.6	-	11.8	10.0	-	12.1	11.8	-	15.5	10.4	-
Average	23.5	16.4	+7.1	24.1	20.4	+3.7	20.5	20.7	—.2	25.4	19.7	+5.7
Rye, straw:												
1913	5,075	3,725	-	6,220	4,060	-	5,180	3,860	-	5,220	4,380	-
1921	1,515	1,010	-	1,340	1,240	-	1,340	1,490	-	1,820	1,320	-
Average	3,295	2,368	+927	3,780	2,650	+1,130	3,260	2,675	+585	3,520	2,850	+670

[1] Uncertainty as to accuracy, as the labels were accidentally moved.

TABLE 8. — *The Interrelation of Lime and Fertilizer (Yields per Acre)* — Concluded.

Crop.	Phosphoric Acid and Nitrogen (Plot 6).			Potash and Nitrogen (Plot 7).			Phosphoric Acid and Potash (Plot 9).			Complete Fertilizer (Plot 10).		
	Limed.	Unlimed.	Apparent Gain from Liming.	Limed.	Unlimed.	Apparent Gain from Liming.	Limed.	Unlimed.	Apparent Gain from Liming.	Limed.	Unlimed.	Apparent Gain from Liming.
Grass and clover:												
1903	3,180	1,830	-	2,190	1,820	-	920	620	-	2,830	2,330	-
1904	3,130	2,330	-	2,380	1,970	-	6,160	940	-	7,240	2,820	-
1908	4,600	3,720	-	3,800	3,240	-	3,240	800	-	4,730	4,240	-
1909	2,750	2,010	-	2,980	1,240	-	3,840	920	-	2,520	1,790	-
1914	3,849	2,540	-	4,080	2,000	-	4,120	1,030	-	6,110	2,600	-
1915	4,190	1,280	-	5,560	960	-	5,220	580	-	5,800	900	-
Average	3,617	2,285	+1,332	3,498	1,872	+1,626	3,967	815	+3,152	4,872	2,447	+2,425
Beans (green weight), 1918 .	2,200	1,980	+220	1,360	2,380	+1,980	3,010	1,680	+1,360	3,740	2,500	+1,240
Cabbage, 1917	27,410	23,160	+4,280	28,000	1,000	+27,000	32,720	13,880	+18,840	45,400	33,360	+12,040
Corn, grain (bushels):												
1905	29.2	20.2	-	29.5	12.5	-	34.2	11.3	-	43.1	36.2	-
1916	41.3	43.3	-	45.7	25.1	-	48.1	30.3	-	51.2	38.3	-
Average	35.3	31.8	+3.5	37.6	18.8	+18.8	41.2	20.8	+20.4	47.2	37.8	+9.4
Grain, stover:												
1905	3,680	3,600	-	3,720	2,960	-	3,400	4,520	-	4,840	5,840	-
1916	2,800	3,600	-	3,800	2,900	-	4,000	2,500	-	4,200	4,200	-
Average	3,240	3,600	—360	3,760	2,930	+830	3,700	3,510	+190	4,520	5,020	—500
Soy beans (bushels):												
1906	9.5	6.9	-	14.1	9.7	-	10.3	6.9	-	14.1	7.9	-
1910	18.6	14.5	-	19.0	8.3	-	19.7	4.8	-	16.6	8.3	-
1911	6.9	10.9	-	20.7	14.5	-	15.9	11.3	-	20.2	17.1	-
Average	11.7	10.8	+.9	17.9	10.8	+7.1	15.3	8.7	+6.6	17.0	11.1	+5.9

Soy beans, straw:												
1906	760	520	–	780	740	–	600	420	–	920	400	–
1910	4,120	2,160	–	1,820	1,520	–	1,460	1,040	–	3,240	2,200	–
1911	2,600	2,290	–	3,000	2,360	–	2,880	3,370	–	3,830	3,610	–
Average	2,493	1,657	+836	1,867	1,540	+327	1,647	1,610	+37	2,663	2,070	+593
Onions (bushels):												
1899	145.4	143.1	–	200.0[1]	3.1	–	183.8	40.4[1]	–	224.6	46.2[1]	–
1900	202.3	225.8	–	310.8	9.2	–	380.0	159.6	–	488.5	136.9	–
Average	173.9	184.5	–10.6	255.4	6.2	+249.2	281.9	100.0	+181.9	356.5	91.5	+265.0
Potatoes (bushels), 1902	100.3	98.0	+2.3	75.6	77.3	–1.7	113.7	91.7	+22.0	132.6	127.3	+5.3
Rye, grain (bushels):												
1913	35.3	27.9	–	35.3	22.9	–	31.1	17.1	–	35.7	21.8	–
1921	15.7	16.4	–	13.9	10.0	–	6.1	9.6	–	7.1	7.5	–
Average	25.5	22.2	+3.3	24.6	16.5	+8.1	18.6	13.4	+5.2	21.4	14.7	+6.7
Rye, straw:												
1913	5,020	4,240	–	5,620	4,720	–	5,260	3,640	–	5,600	3,780	–
1921	1,760	960	–	1,440	1,240	–	2,360	1,300	–	1,280	800	–
Average	3,390	2,600	+790	3,530	2,980	+550	3,810	2,470	+1,340	3,440	2,290	+1,150

[1] Uncertainty as to accuracy, as the labels were accidentally moved.

TABLE 9. — *Yields per Acre, Limed Portion of Field.*

Treatment.	Corn (2 Crops) (Bushels).		Grass and Clover (6 Crops) (Pounds).		Soy Beans (3 Crops) (Bushels).	
	Yield.	Gain from Use of Potash.[1]	Yield.	Gain from Use of Potash.[1]	Yield.	Gain from Use of Potash.[1]
Nitrogen alone	14.4		2,490		8.3	
Nitrogen and potash	37.6	23.2	3,498	1,008	17.9	9.6
Phosphoric acid alone	21.7		1,407		6.2	
Phosphoric acid and potash	41.2	19.5	3,967	2,560	15.3	9.1
Nitrogen and phosphoric acid	35.3		3,617		11.7	
Complete fertilizer	47.2	11.9	4,872	1,255	17.0	5.3

[1] By difference.

The large and consistent differences secured through the use of potash indicate that whatever effect the lime may have had on the availability of soil potash was relatively insignificant. This checks the results secured on the South Soil Test, as already discussed.

Miscellaneous Effects of Fertilizers on Crops.

Even though the fertilizer applications were in some cases doubled, as indicated on page 142, either the soil conditions were unfavorable or the amount of plant food applied was too small to give satisfactory crops of onions or potatoes. The yield of 488 bushels of onions on the limed complete fertilizer plot in 1900 is indeed well above the average, but still is not a large yield. In 1898 and likewise in 1901, the crop was a failure. The yield records do, however, indicate two things very strongly: first, the great importance to the onion crop of maintaining a suitable reaction of the soil; and second, the need by the crop of large quantities of all three of the essential plant foods. The potato crops of 1897 and 1902 were virtual failures.

The cabbage crop of 1917 was remarkably satisfactory and furnishes several illustrations of the fact that crops of the same size may be secured through radically different plant food treatments. As an illustration, the crop on the limed half of Plot 9, which in 1917 had been receiving phosphoric acid and potash annually for twenty-seven years, was the same as the crop on complete fertilizer without lime. Neither one of these, however, approached the crop produced with complete fertilizer and lime. Again, the crop on the limed portion of Plot 6, which had received no potash for twenty-seven years, was almost identical with that on the limed portion of Plot 7, which had received no phosphoric acid for the

PLATE I.

CROP RESPONSE TO NITROGEN AND LIME.

CABBAGES, CROP OF 1917.

Potash and phosphoric acid with lime. Yield per acre: good, 25,000 pounds; poor, 7,720 pounds.

Potash, phosphoric acid and nitrogen without lime. Yield per acre: good, 26,040 pounds; poor, 7,320 pounds.

A. Lime versus *Nitrogen.*

A very fair crop was produced with potash and phosphoric acid plus lime, or with complete fertilizer without lime.

Potash and phosphoric acid without lime. Yield per acre: good, 6,320 pounds; poor, 7,560 pounds

Potash, phosphoric acid and nitrogen with lime. Yield per acre: good, 42,480 pounds; poor, 2,920 pounds.

B. Nitrogen with and without Lime.

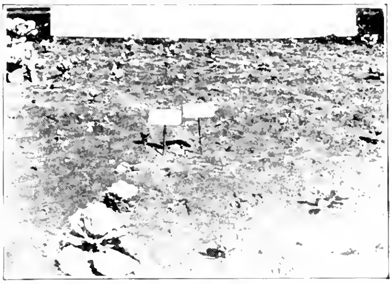
The lower left compared with upper right indicates the effect of nitrogen without lime: upper left compared with lower right the effect of nitrogen with lime.

PLATE II.

EFFECT OF ACIDULATED PHOSPHATE IN NEUTRALIZING THE EFFECT OF "SOIL ACIDITY."

CABBAGES, CROP OF 1917.

Nitrogen and phosphoric acid without lime. Yield per acre: good, 13,560 pounds; poor, 9,600 pounds.



Nitrogen and potash without lime. Yield per acre: good, 160 pounds; poor, 840 pounds. (An absolute crop failure.)

A. Without Lime.

The omission of phosphoric acid under acid soil conditions was fatal.

Nitrogen and phosphoric acid with lime. Yield per acre: good, 21,560 pounds; poor, 5,880 pounds.

Nitrogen and potash with lime. Yield per acre: good, 20,000 pounds; poor, 7,600 pounds.

B. With Lime.

A fair crop was produced without phosphoric acid, although, as shown on the opposite page, complete treatment gave much the larger crop.

same length of time. In both cases the crop was fairly satisfactory. On the other hand, nitrogen and phosphoric acid without lime gave an immensely larger crop than did nitrogen and potash without lime, — once again indicating that under certain conditions phosphorus functions in reducing need for lime, or in neutralizing the effects of soil acidity. It is also of interest to note that the yield of cabbages classified as "poor" is less absolutely, and very much less relatively, on the high-yielding plots than on the low-yielding plots.

General Summary.

The more important conclusions which may be drawn from this work, in their application to the fertility practice of Massachusetts farmers, are as follows: —

1. The kind of crop being grown and the cropping system followed determine the fertilizer needs of crops fully as much as does the soil type.

2. Where the soil is farmed without live stock, and no manure returned to the land, a complete fertilizer is more certain to bring satisfactory results than is any other fertilizer treatment.

3. The nitrogen response of crops is affected by nearness in the rotation to a legume crop, and likewise by the kind of crop. The tests indicate that where corn is grown either the first or second year following a legume, the use of fertilizer nitrogen does not bring anything more than a moderate return. The character of the season does not seem to have a dominant influence on the functioning of this plant food when applied in artificial form.

4. Where the whole crop is removed and manure not returned to the soil, large returns from the use of potash may be expected. As a corollary, the greater the extent to which crops are removed, the greater relatively will be the need for fertilizer potash; and on the other hand, the greater the extent to which crops produced are fed on the farm and manure returned, the lower will be the need for this plant food. The lesson therefore applies most particularly to farms where the supply of manure is deficient, and particularly to those where hay is cut for market, or where tobacco, onions or other money crops are raised continuously on the same land.

5. The use of lime in the cropping system followed has increased very significantly the size of crops. Apparently, however, it has had no effect on the availability of soil potash.

6. The tests show the great dependence of clover on a generous supply of lime, potash and phosphoric acid. They demonstrate a principle which is believed to be of almost universal application.

7. Soluble phosphates function in reducing, although not in eliminating, the crop damage caused by "acidity" or lack of lime.

8. Crops vary enormously in their response to the different plant foods. Except for corn and for grass and clover, however, the number of tests on individual crops is too small to permit of safe generalization.

APPENDIX.

TABLE I. — *South Soil Test (Yields per Acre).*

Year.	Crop.		Plot 1, Nitrate of Soda.	Plot 2, Dissolved Boneblack.	Plot 3, Check.	Plot 4, Muriate of Potash.	Plot 5, Lime.	Plot 6, Check.	Plot 7, Manure.	Plot 8, Nitrate and Boneblack.	Plot 9, Check.	Plot 10, Nitrate and Muriate.	Plot 11, Bone-black and Muriate.	Plot 12, Check.	Plot 13, Plaster.	Plot 14, Nitrate, Boneblack and Muriate.
1889	Corn	Grain (bushels)	31.25	30.00	24.75	49.25	30.75	23.50	57.50	37.00	36.75	53.00	58.00	32.50	31.25	61.50
		Stover (pounds)	1,660	1,940	1,440	2,980	1,740	1,400	4,200	2,100	2,080	3,020	3,960	2,100	1,880	4,180
1890	Corn	Grain (bushels)	45.60	49.50	43.75	62.60	51.80	45.56	59.75	50.37	42.50	53.94	65.90	52.20	52.00	71.00
		Stover (pounds)	3,750	3,590	4,850	4,590	3,660	3,500	5,520	3,260	3,130	4,235	4,880	3,525	3,540	5,320
1891	Oats	Grain (bushels)	33.13	18.13	18.13	24.07	24.69	20.31	38.44	29.07	16.56	29.69	25.94	17.50	15.94	33.13
		Straw (pounds)	2,500	1,490	1,490	1,750	1,300	1,400	4,620	2,210	1,260	2,270	1,630	1,350	1,240	3,010
1892	Grass and clover	Hay (pounds)	1,920	960	1,160	1,160	1,020	780	2,960	2,060	2,460	2,060	2,560	1,200	960	2,860
		Rowen (pounds)	720	800	640	1,400	720	600	2,240	640	660	1,040	1,900	840	680	1,340
1893	Grass and clover	Hay (pounds)	2,260	1,070	1,000	1,380	1,020	920	3,640	2,080	720	2,440	1,440	780	520	2,600
		Rowen pounds)	520	360	330	950	400	380	2,240	520	460	840	1,680	480	480	1,340
1894	Corn	Grain (bushels)	22.5	18.3	21.5	41.7	18.4	13.0	54.7	20.9	29.2	44.6	49.5	16.7	23.7	51.0
		Stover (pounds)	2,860	2,300	2,280	3,600	2,500	1,780	3,760	1,840	2,460	4,100	3,820	1,620	2,740	3,780
1895	Rye	Grain (bushels)	15.36	11.79	11.43	16.06	13.21	13.21	34.28	12.68	12.50	11.78	15.00	11.07	13.21	26.45
		Straw (pounds)	2,000	1,900	1,700	2,160	1,900	1,880	5,080	2,040	1,740	1,920	2,420	1,480	1,820	3,960
1896	Soy beans	Beans (bushels)	2.4	4.8	5.5	13.1	2.4	4.1	30.4	5.2	7.6	14.1	15.5	6.9	5.5	22.1
		Straw (pounds)	680	800	890	1,000	540	720	4,600	790	780	940	1,040	640	900	1,480
1897	Mustard (pounds)		-	-	-	-	20	-	8,500	900	-	-	500	-	-	5,100
1898	Corn	Grain (bushels)	20.6	18.5	9.8	19.8	10.4	16.9	67.7	32.0	12.5	10.9	41.2	10.5	21.9	55.9
		Stover (pounds)	2,210	1,400	1,050	1,540	1,000	1,100	3,800	1,700	800	1,300	2,440	650	1,300	2,600
1899	Corn	Grain (bushels)	13.7	3.5	3.9	49.7	7.2	5.0	75.9	21.4	5.9	47.9	59.9	3.6	6.6	72.9
		Stover (pounds)	1,160	620	730	2,760	1,100	820	5,350	1,220	840	2,360	3,160	680	990	4,450

1900	Grass and clover	Hay (pounds)	2,460	1,000	800	1,140	880	720	4,160	2,540	1,100	3,000	1,600	1,100	900	2,300
1901	Grass and clover	Hay (pounds)	900	300	400	600	500	300	3,600	1,200	400	2,100	1,900	400	200	3,300
		Rowen (pounds)	550	370	240	700	360	270	2,700	530	360	900	1,500	380	200	1,100
1902	Corn	Grain (bushels)	7.3	11.4	10.4	47.7	4.9	10.4	68.7	11.2	9.2	53.4	55.9	8.8	14.6	56.2
		Stover (pounds)	1,180	1,780	1,480	4,760	860	800	6,220	1,380	1,360	3,540	4,640	1,300	1,880	4,540
1903	Corn	Grain (bushels)	.56	.94	.94	16.61	.15	1.06	37.39	3.89	1.28	18.00	20.39	1.78	2.06	25.56
		Stover (pounds)	360	360	300	1,880	160	1,200	3,600	800	340	2,200	2,320	400	400	3,040
1904	Corn	Grain (bushels)	7.11	3.89	4.33	46.89	2.67	3.44	50.00	15.11	8.78	47.67	53.11	6.33	7.44	47.78
		Stover (pounds)	1,200	960	870	3,760	820	740	4,000	1,500	1,180	3,560	3,940	1,000	1,100	3,700
1905	Grass and clover	Hay (pounds)	2,600	400	600	2,100	1,000	700	3,200	2,000	1,200	1,500	2,300	1,400	700	1,700
1906	Grass and clover	Hay (pounds)	1,400	760	910	690	890	660	2,940	2,200	820	2,400	1,790	950	640	3,000
		Rowen (pounds)	520	295	300	440	260	325	2,670	520	390	470	1,220	410	320	1,100
1907	Corn	Grain (bushels)	1.00	.81	2.00	23.31	1.25	2.25	72.50	10.06	3.81	31.13	30.13	3.38	7.75	38.31
		Stover (pounds)	720	700	1,000	6,000	900	1,100	6,900	2,500	1,100	5,400	6,500	800	1,200	5,500
1908	Oats and crimson clover	Oat hay (pounds)	2,430	1,600	850	3,300	610	720	7,600	3,510	780	4,420	4,680	675	1,090	6,600
1909	Buckwheat (weight as cut, pounds)		5,808	2,299	3,388	6,897	3,872	4,054	16,214	7,744	4,235	10,043	9,922	3,993	4,840	14,036
1910	Corn	Grain (bushels)	14.28	5.57	3.86	24.65	5.07	9.21	57.43	8.93	4.57	26.72	37.14	17.21	13.86	41.57
		Stover (pounds)	1,700	1,800	400	2,120	500	1,100	3,700	1,900	700	2,200	2,300	1,700	800	3,080
1911	No crop		–	–	–	–	–	–	–	–	–	–	–	–	–	–
1912	Crimson clover[1]		–	–	–	–	–	–	–	–	–	–	–	–	–	–
1913	Corn	Grain (bushels)	22.6	11.0	11.7	52.6	8.7	8.4	66.8	–	–	51.2	49.7	29.1	11.0	44.4
		Stover (pounds)	2,420	2,180	2,240	4,360	2,460	1,700	5,140	–	–	3,500	4,040	2,740	1,880	3,840
1914	Soy beans (total weight, pounds)		3,500	900	1,000	6,000	1,200	1,800	11,500	–	–	9,100	7,700	1,700	1,700	9,800
1915	Corn	Grain (bushels)	22.86	10.00	8.50	40.86	5.29	10.93	60.79	–	–	31.25	37.58	16.5	10.92	35.15
		Stover (pounds)	1,490	760	615	1,980	635	720	3,520	–	–	3,365	3,250	960	805	3,400
1916	Sweet clover[1]		–	–	–	–	–	–	–	–	–	–	–	–	–	–
1917	Corn	Grain (bushels)	34.2	18.1	12.7	40.9	13.8	13.9	40.8	–	–	46.1	46.3	15.7	21.7	36.0
		Stover (pounds)	1,900	1,600	2,400	3,300	1,700	1,500	5,200	–	–	3,500	3,300	2,100	1,400	5,400
1918	Alfalfa	First cutting (pounds)	1,020	180	140	1,710	120	0	4,050	–	–	1,600	1,920	640	150	1,960
		Second cutting (pounds)	1,480	1,590	1,005	1,815	1,170	735	3,035	–	–	2,160	2,415	1,180	1,090	1,555

[1] No weights taken.

SOUTH SOIL TEST.

1889. An 8-rowed flint corn. 80 pounds per bushel.

1890. An early dent corn. 80 pounds per bushel.

1891. Variety, Early Race Horse. There was sown with the oats the following mixture of grass and clover: timothy, 12 pounds; redtop, 8 pounds; red clover, 6 pounds; white clover, 2 pounds; alsike clover, 3 pounds.

1894. Pride of the North. 80 pounds per bushel.

1895. After rye, the land was plowed and sown to white mustard, without additional fertilizer (July 31). Germination was quick and even, but except on the plots where manure or phosphate, lime and plaster have been applied, there was almost absolutely no growth.

1896. Medium Green. A wet fall. Beans not ripened well. Plots 1, 2, 5, 6 and 8 molded a little in stack.

1897. Unfavorable weather conditions destroyed the onions and cabbages. Sowed mustard August 14. Only four plots furnished sufficient growth to cut and weigh. Double application of manure and fertilizer made.

1898. Pride of the North. 80 pounds per bushel. On July 29 mustard was sown, covering plots and division strips. The mustard came up on all plots, but made no growth except on Plots 7 and 14, and even here was very spindling and light.

1899. Pride of the North. 80 pounds per bushel. Ears and leaves eaten by cows for 1 rod on the north end of Plot 7. Weights of stover on the best plots low because the corn, making a normal growth, was ripe long before it was cut and the stover became dry. Except on Plots 4, 7, 10, 11 and 14, the ears were very poor, immature and small.

1900. Spring sowing: awnless brome, 20 pounds; tall oat, 5 pounds; Italian rye, 8 pounds; meadow fescue, 8 pounds; orchard, 8 pounds; yellow oat, 5 pounds; medium red clover, 16 pounds.

1901. Hay; no clover except where potash has been applied. Brome grass most abundant on lime plots.

1902. From 1902 on the application of lime and plaster is at the rate of 40 pounds per plot instead of 20 pounds as heretofore.

1902. Pride of the North. 90 pounds per bushel. Corn weighed two weeks after husking. Stover varies greatly as to moisture.

1903. Pride of the North. 90 pounds per bushel. Stover well dried out.

1904. Pride of the North. 90 pounds per bushel.

1905. Spring sowing: timothy, 18 pounds; redtop, 8 pounds; meadow oat, 6 pounds; Italian rye, 8 pounds; awnless brome, 6 pounds; orchard, 15 pounds; mammoth red clover, 5 pounds; alsike, 4 pounds.

1907. Rustler white dent. 80 pounds per bushel. Weighed after drying out in glasshouse.

1908. Lincoln oats. A part of the oats on Plot 8, measuring 602 square feet, has been destroyed by Mr. Fitts' hens. Correction for same is made in the record of the yield.

Crimson clover, poor, plowed under.

1909. Product of a strip 10 feet wide across plots. The rest plowed under. Weighed as cut. Winter vetch and rye sown on September 30.

1910. 70 pounds per bushel. Fertilizer for Plot 11 probably applied to Plot 12 by mistake. Sowed alsike clover in corn, August 2.

1911. No crop. Flint Laboratory takes Plots 8 and 9. Fertilizer applied as usual, field plowed and kept cultivated and free from weeds.

1912. Crimson clover, poor, no crop.

1913. Rustler white dent. 70 pounds per bushel. Weighed after being dried in glasshouse.

1914. Medium Green. Did not mature.

1915. Longfellow. 70 pounds per bushel.

1916. Sweet clover. Mostly weeds; cut and removed without weighing.

1917. Sweet clover plowed under.

Corn, Early Canada Flint. Plot 12 received about one-half the fertilizer for Plot 11. This amount was made up on Plot 11. 70 pounds per bushel.

1918. Alfalfa, sown Aug. 20, 1917, in corn. Second cutting, Plots 2, 3, 5, 12 and 13 mostly grass and weeds; Plot 6 all grass and weeds.

TABLE II. — *Precipitation in Inches.*

Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
1889 . .	3.29	1.45	1.46	2.42	4.71	5.01	10.52	2.72	3.17	4.58	6.04	3.57	48.94
1890 . .	2.61	4.20	5.37	1.73	5.39	1.53	5.63	4.88	5.85	7.13	1.32	2.86	48.50
1891 . .	6.75	4.23	2.99	2.66	1.97	4.75	5.28	4.18	2.66	2.94	2.99	5.40	46.80
1892 . .	5.85	1.90	2.40	0.76	6.28	3.46	4.41	6.47	2.16	0.66	4.98	1.01	40.34
1893 . .	3.33	5.75	3.66	4.41	5.02	3.32	2.59	3.49	2.82	4.88	2.81	4.86	46.94
1894 . .	2.16	1.74	1.77	1.83	4.00	3.13	1.55	0.31	4.63	4.85	3.14	3.53	32.64
1895 . .	3.87	1.05	2.71	5.56	2.07	2.76	3.87	3.46	5.04	4.77	5.36	3.94	44.46
1896 . .	1.07	4.67	6.11	1.32	2.58	2.57	4.96	3.84	5.41	3.23	3.03	0.87	39.66
1897 . .	3.00	2.52	3.53	2.42	4.38	6.65	14.51	4.29	1.94	0.73	5.85	7.23	57.05
1898 . .	7.15	3.80	1.63	3.73	5.61	3.69	4.09	6.85	3.65	6.27	5.48	2.30	54.25
1899 . .	2.80	3.56	7.13	1.79	1.28	4.13	4.89	2.00	7.90	1.84	2.17	2.00	41.49
1900 . .	4.08	8.12	5.76	1.85	3.78	3.65	4.67	4.11	3.67	3.72	5.87	2.40	51.68
1901 . .	1.81	0.62	5.66	5.95	6.91	0.87	3.86	6.14	4.17	3.88	2.08	7.77	49.72
1902 . .	1.72	3.54	5.29	3.31	2.32	4.54	4.66	4.65	5.83	5.59	1.27	4.27	46.99
1903 . .	3.28	4.27	6.40	2.30	0.48	7.79	4.64	4.92	1.66	2.72	2.04	3.95	44.45
1904 . .	4.74	2.45	4.48	5.73	4.55	5.35	2.62	4.09	5.45	1.74	1.35	2.75	45.30
1905 . .	3.90	1.70	3.66	2.56	1.28	2.86	2.63	6.47	6.26	2.27	2.06	3.15	38.80
1906 . .	2.18	2.73	4.90	3.25	4.95	2.82	3.45	6.42	2.59	5.69	1.98	4.49	45.45
1907 . .	2.73	1.92	1.82	1.98	4.02	2.36	3.87	1.44	8.74	5.00	4.50	3.89	42.27
1908 . .	2.25	3.53	2.86	1.97	4.35	0.76	3.28	4.27	1.73	1.57	1.06	3.05	30.68
1909 . .	3.56	5.16	3.01	5.53	3.36	2.24	2.24	3.79	4.99	1.23	1.06	2.95	39.12
1910 . .	6.14	5.08	1.37	3.07	2.67	2.65	1.90	4.03	2.86	0.93	3.69	1.72	36.11
1911 . .	2.36	2.18	3.80	1.87	1.37	2.02	4.21	5.92	3.41	8.81	3.84	4.42	44.21
1912 . .	2.18	3.16	5.70	3.92	4.34	0.77	2.61	3.22	2.52	2.07	4.03	4.04	38.56
1913 . .	3.98	2.94	6.38	3.30	4.94	0.90	1.59	2.26	2.56	5.16	2.11	3.38	39.50
1914 . .	3.72	3.36	5.52	6.59	3.56	2.32	3.53	5.11	0.52	2.09	2.62	2.89	41.83
1915 . .	6.52	7.02	0.12	3.99	1.20	3.00	9.13	8.28	1.37	2.89	2.20	5.86	51.58
1916 . .	2.56	5.27	3.97	3.69	3.21	5.34	6.85	2.49	5.08	1.01	3.29	2.85	45.61
1917 . .	3.64	1.98	4.08	1.83	4.13	5.27	3.36	7.06	2.42	6.60	0.63	2.56	43.56
1918 . .	4.11	2.99	2.91	2.78	2.47	4.01	1.84	2.22	7.00	1.32	2.87	2.95	37.47
1919 . .	2.02	2.80	4.22	2.37	6.20	1.09	4.17	4.81	4.25	1.81	6.20	1.48	41.42
1920 . .	2.74	4.45	3.63	4.71	3.65	6.26	2.06	3.62	6.74	1.54	5.62	6.02	51.04
1921 . .	2.00	2.38	3.57	6.47	4.56	3.87	6.00	2.35	1.84	1.08	6.20	1.90	42.22

Table III. — *Temperature and Frost Records.*

Year.	Mean Hourly Temperature (Degrees Fahrenheit).						Last Spring Frost.	First Fall Frost.
	April.	May.	June.	July.	August.	September		
1889	49.3	61.4	67.7	69.5	65.5	61.9	May 26	Sept. 21
1890	46.5	57.1	65.3	69.8	67.2	59.7	May 12	Sept. 25
1891	49.4	57.3	66.6	68.2	70.2	65.3	May 19	Oct. 12
1892	48.7	56.1	70.3	72.2	70.0	60.6	May 10	Sept. 30
1893	44.7	58.7	69.0	71.4	71.0	58.1	May 8	Sept. 3
1894	47.9	58.7	69.4	73.5	69.3	64.8	May 22	Aug. 22
1895	46.9	61.3	70.5	69.3	70.4	63.8	May 17	Aug. 22
1896	49.2	62.4	65.0	70.7	68.2	59.2	May 1	Sept. 24
1897	46.5	57.1	61.8	70.5	66.0	59.8	May 8	Sept. 22
1898	43.0	55.6	66.0	70.9	69.7	63.0	April 27	Sept. 21
1899	46.1	55.7	67.4	70.1	68.0	59.7	May 4	Sept. 14
1900	46.9	55.4	67.1	70.6	70.1	63.8	May 29	Sept. 15
1901	46.8	56.2	68.0	72.5	69.9	62.1	May 6	Sept. 26
1902	47.3	57.0	63.5	67.8	66.1	60.3	May 14	Sept. 6
1903	46.9	59.2	59.6	68.9	62.0	61.3	May 2	Sept. 25
1904	42.5	60.1	65.0	69.8	66.4	59.8	April 23	Sept. 22
1905	45.6	56.9	64.4	71.1	65.8	59.1	May 24	Sept. 12
1906	45.1	56.7	66.1	70.1	70.5	64.0	May 20	Sept. 25
1907	41.5	51.8	63.9	70.0	66.1	61.3	May 22	Sept. 27
1908	45.1	59.2	67.6	72.5	66.6	62.9	June 3	Sept. 16
1909	44.4	55.5	66.4	68.7	66.5	60.5	May 12	Oct. 13
1910	50.6	56.1	63.8	72.1	67.1	61.1	May 6	Sept. 23
1911	43.7	61.9	64.5	73.7	67.8	60.2	May 5	Sept. 14
1912	45.2	58.1	65.0	71.6	66.4	61.2	May 1	Aug. 31
1913	47.6	55.6	66.4	71.4	69.5	59.7	May 15	Sept. 10
1914	42.1	59.0	64.4	67.7	68.9	60.2	May 16	Sept. 28
1915	49.9	54.1	64.2	68.9	66.0	64.2	May 20	Sept. 23
1916	43.9	55.9	61.1	71.6	69.5	60.8	May 19	Sept. 17
1917	42.9	49.3	65.3	71.7	70.9	57.0	May 18	Sept. 11
1918	45.7	62.1	62.9	70.1	70.5	57.6	April 26	Sept. 11
1919	45.4	57.6	68.4	71.8	65.8	61.7	May 1	Sept. 18
1920	43.2	54.6	64.5	68.3	70.2	62.8	April 26	Oct. 7
1921	51.5	58.9	66.9	73.4	66.9	65.6	May 12	Oct. 9

TABLE IV. — *North Soil Test (Yields per Acre).*

Year.	Crop.		Plot 1, Check.	Plot 2, Nitrate of Soda.	Plot 3, Dissolved Boneblack.	Plot 4, Check.	Plot 5, Muriate.	Plot 6, Nitrate and Boneblack.	Plot 7, Nitrate and Muriate.	Plot 8, Check.	Plot 9, Boneblack and Muriate.	Plot 10, Nitrate, Boneblack and Muriate.	Plot 11, Plaster.	Plot 12, Check.
1890	Corn	Grain (bushels)	51.2	53.3	57.5	51.3	69.3	59.4	67.6	48.1	71.0	71.9	51.5	47.5
		Stover (pounds)	5,620	5,700	4,310	4,190	5,740	4,330	5,430	3,890	5,740	5,820	4,240	4,180
1891	Potatoes	Large (bushels)	25.67	26.33	35.67	17.33	63.33	32.33	61.33	16.67	49.33	58.33	15.67	11.67
		Small (bushels)	4.33	4.67	5.67	5.67	4.00	6.33	5.00	2.67	3.33	6.33	6.67	6.00
1892	Soy beans	Beans (bushels)	12.83	13.67	10.33	11.75	15.42	13.00	16.08	13.08	12.92	13.67	13.17	12.67
		Straw (pounds)	1,000	[illegible]	940	1,940	1,110	1,260	1,100	960	900	960	960	1,400
1893	Oats	Grain (bushels)	18.13	42.19	41.56	43.75	52.19	45.94	40.69	42.81	47.50	46.56	41.25	42.81
		Straw (pounds)	1,920	1,880	1,750	1,700	2,220	2,650	2,650	1,900	2,760	2,920	1,720	1,940
1894	Grass and clover	Hay (pounds)	640	1,320	680	280	240	1,500	680	200	440	1,620	360	220
1895	Grass and clover	Hay (pounds)	1,000	1,000	640	650	1,200	1,310	1,680	640	920	1,860	620	820
		Rowen (pounds)	–	–	–	–	310	–	–	–	220	200	–	–
1896	Cabbage	Hard (pounds)	1,200	3,240	2,080	2,640	11,520	12,000	5,800	3,800	21,200	26,200	3,320	2,240
		Soft (pounds)	9,680	8,680	8,500	8,900	7,480	9,080	4,200	6,880	7,490	6,680	6,600	4,200
1896	Turnips (pounds)		14,400	12,100	9,800	9,800	10,200	14,000	14,000	9,800	24,200	23,000	8,000	7,000
1897	Potatoes	Large (bushels)	15.50	8.87	22.00	30.00	42.00	88.33	29.67	20.67	54.00	55.33	35.83	38.00
		Small (bushels)	52.00	35.67	32.00	23.17	35.50	33.00	38.83	38.67	30.67	38.50	23.00	26.50
1898	Onions	Tops and bulbs (pounds)	940	830	1,640	1,310	1,540	9,640	650	920	2,100	4,360	680	1,540
		Merchantable (bushels)	.8	2.5	5.[illegible]	1.2	.8	116.8	.2	.8	1.9	16.3	.5	1.4
1899	Onions	Sound (bushels), unlimed	2.69	18.65	6.53	5.19	3.97	143.10	3.07	2.88[1]	40.38[1]	46.15[1]	4.01[1]	4.04
		Sound (bushels), limed	4.12	91.43	12.31	26.15	161.75[1]	115.10	200.00[1]	16.93[1]	183.80	224.60	6.35[1]	30.39[1]
1900	Onions	Sound (bushels), unlimed	6.15	50.00	17.31	77.69	37.69	225.77	9.23	38.46	159.62	136.92	4.62	23.46
		Sound (bushels), limed	41.54	155.00	37.69	132.31	383.46	292.31	310.77	107.69	380.00	488.46	23.08	102.31
1901	Onions	Tops and bulbs (pounds), unlimed	1,680	2,400	1,880	1,400	3,000	8,800	2,400	800	10,000	18,600	1,400	1,400
		Tops and bulbs (pounds), limed	3,200	4,200	2,600	2,200	11,200	8,000	13,800	2,480	13,200	22,600	2,960	2,720

[1] Uncertainty as to accuracy, as the labels were accidentally moved.

TABLE IV. — *North Soil Test (Yields per Acre)* — Concluded.

Year.	Crop.		Plot 1, Check.	Plot 2, Nitrate of Soda.	Plot 3, Dissolved Boneblack.	Plot 4, Check.	Plot 5, Muriate.	Plot 6, Nitrate and Boneblack.	Plot 7, Nitrate and Muriate.	Plot 8, Check.	Plot 9, Boneblack and Muriate.	Plot 10, Nitrate, Boneblack and Muriate.	Plot 11, Plaster.	Plot 12, Check.
1902	Potatoes	Large (bushels), unlimed	27.7	30.0	39.3	31.3	58.0	69 3	51.3	35.3	73.7	110.3	24.7	24.5
		Small (bushels)	24.0	20.7	20.0	22.7	15.3	28.7	26 0	29.3	18.0	17 0	16.0	21.7
		Large (bushels), limed	21.3	27.3	26.0	22.7	69 0	71.3	58.3	32.7	93.7	115.3	24 3	30.3
		Small (bushels)	27.7	20.3	22.0	21.3	12.7	29.0	17.3	21.3	20.0	17.3	13.7	17.3
1903	Grass and clover	Hay (pounds), unlimed	360	1,520	950	550	660	1,830	1,820	450	620	2,330	430	420
		Hay (pounds), limed	1,150	3,140	1,560	1,010	950	3,180	2,190	570	920	2,830	480	1,140
1904	Grass and clover	Hay (pounds), unlimed	1,060	1,960	1,000	560	600	2,120	1,920	560	860	2,200	560	640
		Rowen (pounds)	140	60	60	30	70	210	50	40	80	620	20	10
		Hay (pounds), limed	800	1,600	680	560	1,920	2,320	1,860	940	3,600	4,400	600	1,280
		Rowen (pounds)	80	90	120	130	780	810	520	500	2,560	2,840	80	240
1905	Corn	Grain (bushels), unlimed	8.71	13.88	7.76	5.41	5.65	20.24	12.47	4.47	11.29	36.24	10.59	16.00
		Stover (pounds)	3,100	480	3,400	3,160	4,040	3,600	2,960	1,800	4,520	5,840	2,240	3,140
		Grain (bushels), limed	7.88	9.06	5.88	8.94	18 35	29.18	29 53	18 12	34 24	43.06	19 53	20.00
		Stover (pounds)	2,520	3,960	2,640	2,920	4,400	3,680	3,720	3,520	3,400	4,840	2,320	2,280
1906	Soy beans	Beans (bushels), unlimed	10.86	4.48	5.52	13.1	8.28	6.90	9.66	7.76	6.90	7.93	5.34	10.34
		Straw (pounds),	690	440	380	630	520	520	740	600	420	400	400	720
		Beans (bushels), limed	5.17	3.45	3.97	6.72	12.41	9.48	14 14	8.79	10.34	14.14	6 03	9.83
		Straw (pounds)	430	490	400	500	720	760	780	520	600	920	400	560
1907	Grass and clover[1]		-	-	-	-	-	-	-	-	-	-	-	-
1908	Grass and clover	Hay (pounds), unlimed	1,340	3,280	940	780	860	3,720	3,240	480	800	4,240	320	440
		Hay (pounds), limed	2,160	3,880	1,600	1,560	2,380	4,600	3,800	1,640	3,240	4,730	1,580	2,220
1909	Grass and clover	Hay (pounds), unlimed	1,280	1,980	1,260	1,180	1,050	2,010	1,240	1,150	920	1,790	380	720
		Hay (pounds), limed	1,570	1,780	1,420	1,520	3,640	2,760	2,980	1,560	3,840	2,520	1,180	1,520
1910	Soy beans	Beans (bushels), unlimed	15.86	14.83	11.38	12.41	8.97	14.48	8.28	9.66	4.83	8.28	10.00	10.34
		Straw (pounds)	1,680	3,140	2,680	1,580	1,680	2,160	1,520	1,840	1,040	2,200	1,300	1,400
		Beans (bushels), limed	20.00	19.31	13.79	17.59	24.83	18.62	18.97	19.31	19.66	16.55	14 48	13.79
		Straw (pounds)	2,920	3,480	2,800	3,180	1,560	4,120	1,820	3,360	1,460	3,240	2,480	3,480

1911	Soy beans	Beans (bushels), unlimed	10.00	4.66	4.66	10.34	14.48	10.86	14.48	10.86	14.31	17.07	8.28	11.05
		Straw (pounds)	1,820	1,450	1,530	1,920	2,160	2,290	2,360	1,890	3,370	3,610	1,320	1,760
		Beans (bushels), limed	1.03	2.07	.86	2.59	20.34	6.90	20.69	15.52	15.86	20.17	1.38	6.21
		Straw (pounds)	940	1,480	950	1,450	2,820	2,600	3,000	3,100	2,880	3,830	1,920	2,640
1912	Soy beans[2]		–	–	–	–	–	–	–	–	–	–	–	–
1913	Rye	Grain (bushels), unlimed	33.6	30.7	29.6	30.4	28.9	27.9	22.9	16.0	17.1	21.8	15.4	16.4
		Straw (pounds)	5,010	4,060	3,860	4,080	4,380	4,240	4,720	2,900	3,640	3,780	3,140	2,880
		Grain (bushels), limed	33.9	36.4	28.9	33.2	35.3	35.3	35.3	30.7	31.1	35.7	35.7	37.9
		Straw (pounds)	5,200	6,220	5,180	3,940	5,220	5,020	5,620	5,080	5,260	5,600	6,000	6,080
1914	Grass and clover	Hay (pounds), unlimed	1,600	2,020	1,490	1,240	1,280	2,540	2,000	820	1,030	2,600	860	600
		Rowen (pounds)	–	–	–	–	–	–	–	–	–	–	–	–
		Hay (pounds), limed	1,840	2,870	1,680	1,830	4,140	3,800	3,080	2,320	3,620	5,310	2,400	2,980
		Rowen (pounds)	–	–	–	200	1,400	40	1,000	600	800	800	200	80
1915	Grass and clover	Hay (pounds), unlimed	920	1,440	1,180	1,020	1,580	1,280	960	520	580	900	460	480
		Rowen (pounds)	–	–	–	–	–	–	–	–	–	–	–	–
		Hay (pounds), limed	1,260	1,400	1,200	1,400	3,700	3,500	3,800	1,600	3,600	4,200	1,100	2,300
		Rowen (pounds)	220	180	180	820	3,050	690	1,760	720	1,620	1,600	280	640
1916	Corn	Grain (bushels), unlimed	21.3	34.5	35.1	28.8	25.9	43.3	25.1	16.3	30.3	38.3	19.9	14.5
		Stover (pounds)	1,600	2,200	3,000	2,600	3,000	3,600	2,900	1,400	2,500	4,200	2,000	1,200
		Grain (bushels), limed	18.7	19.7	21.7	31.5	36.9	41.3	45.7	31.9	48.1	51.2	27.9	26.4
		Stover (pounds)	1,200	1,600	1,600	2,000	2,600	2,800	3,800	2,400	4,000	4,200	2,000	1,600
1917	Cabbage	Good (pounds), unlimed	240	880	2,560	100	180	13,560	160	160	6,320	26,040	720	–
		Poor (pounds)	1,760	2,200	7,240	920	1,400	9,600	840	1,240	7,560	7,320	6,240	1,040
		Good (pounds), limed	10,120	13,640	2,980	7,240	15,360	21,560	20,400	9,320	25,000	42,480	3,980	7,520
		Poor (pounds)	10,160	9,600	6,240	9,240	7,320	5,880	7,600	10,560	7,720	2,920	9,320	9,480
1918	Beans	Total weight (pounds), unlimed	1,460	1,240	960	1,780	2,320	1,980	2,380	1,960	1,680	2,500	1,000	1,520
		Total weight (pounds), limed	960	960	800	1,180	3,840	2,200	4,360	1,180	3,040	3,740	200	700
1919	Hungarian[3]		–	–	–	–	–	–	–	–	–	–	–	–
1920	Rye[4]		–	–	–	–	–	–	–	–	–	–	–	–
1921	Rye	Grain (bushels), unlimed	10.4	10.0	11.8	7.5	10.4	16.4	10.0	9.3	9.6	7.5	4.6	7.3
		Straw (pounds)	1,280	1,240	1,490	960	1,320	960	1,240	940	1,300	800	520	860
		Grain (bushels), limed	15.2	11.8	12.1	14.3	15.5	15.7	13.9	12.1	6.1	7.1	11.1	10.7
		Straw (pounds)	1,680	1,340	1,340	1,480	1,820	1,760	1,440	1,600	2,360	1,280	1,180	1,300

[1] No weights.

[2] Plowed under.

[3] Not harvested.

[4] Spring seeded; not harvested.

NORTH SOIL TEST.

Plot 11.—Plaster, 160 pounds per acre until 1896. In 1896 increased to 400 pounds per acre. In 1902 increased to 800 pounds per acre.

Lime. — The west half of the field has been limed four times as follows: —

1899, 1 ton per acre air-slaked lime.
1901, about 1 ton per acre air-slaked lime.
1907, ½ ton per acre lime.
1916, about 2 tons per acre limestone.

1890. Variety an early dent. Sown in drills, thinned to 6 inches in the row. Cut, stooked and husked instead of being put into the silo as planned. 75 pounds per bushel.
1891. Variety, Beauty of Hebron, seed from Aroostook County, Me. Sprouted unevenly, leaving many vacant places about equally divided among the plots. Somewhat injured by frost.
1892. 60 pounds per bushel.
1893. Plots 3, 6 and 10 lodged badly; 1, 4, 5, 7, 8 and 12 stand fairly well; 5, 7 and 12 quite green; 6, 9, 10 well matured. Fall seeded: timothy, 20 pounds; redtop, 10 pounds; red clover, 6 pounds; alsike, 1 pounds.
1894. Seeded Nov. 29, 1893. Few flower stalks showing when cut. No clover. As weighed from the field the difference in the degree of dryness was quite noticeable.
1895. Hay, mostly redtop except little clover on Plots 10, 9, 7 and 5.
1896. Cabbage on west half and turnips on east half. Turnips rather poor stand, probably weighed tops and roots together.
1897. Fertilizer doubled. Potatoes under 2 ounces called "small."
1898. Fertilizer doubled.
1899. Fertilizer doubled. First liming of west half.
1900. Fertilizer doubled. Field has washed quite badly diagonally. Plot 1 washed some this summer while crop was in. Fall seeded to oats.
1901. Fertilizer doubled. Fall seeded to rye.
1902. Fertilizer doubled. Potatoes, variety, Delaware. Fall seeded: timothy, 18 pounds; redtop, 8 pounds; red clover, 5 pounds; alsike, 4 pounds.
1903. April 4: sow 15 pounds red clover. July 20: the only clover is on limed halves of Plots 9 and 10. Fertilizer doubled
1904. Fertilizer doubled. Second liming of west half. Limed half: hay, very little timothy except on Plot 10; very little redtop on Plots 9 and 10; mostly clover on Plots 5, 9 and 10. Unlimed half: hay, almost no timothy; 50 per cent or over redtop; very little clover on Plots 1, 2, 3, 4, 7, 8 and 12.
1905. Fertilizer back to normal. Sibley's Pride of the North. Total yield at 85 pounds per bushel.
1906. Medium Green. Rather a poor stand.
1907. Spring seeded, 4½ pounds mixed timothy, redtop and clover per plot. Crop mostly weeds; no weights. Third liming of west half.
1908. Mostly redtop. Small amount of clover on Plots 5 and 9, both limed and unlimed. Very little timothy on any plots.
1910. Medium Early Yellow.
1911. Medium Early Yellow.
1912. Medium Yellow soy beans; very poor stand. Plowed under and seeded to rye.
1913. Fall seeded: timothy, 20 pounds; redtop, 10 pounds; red clover, 5 pounds; alsike, 5 pounds.
1914. Rowen practically all clover.
1915. Hay. Unlimed: 1, 2, 3, 4, 11 and 12 mostly all grass; 10 half grass and half clover; 5 mostly all clover; 6, 7, 8 and 9 some clover. Limed: 2, 3 and 6 mostly all grass; 2 and 3 mostly all redtop; 1, 4, 8, 11 and 12 half grass and half clover; 5, 7, 9 and 10 mostly clover.
1916. Longfellow Corn. Fourth liming.
1917. Danish Ballhead.
1918. Yellow Eye Bean. Very unsatisfactory growth. Total weights taken as harvested. Fall seeded to rye.
1919. Plot 1 used for barium-phosphate test. Hungarian on rest of field, not harvested.
1920. Spring seeded to rye. Plowed and fall seeded to rye. No fertilizer applied.
1921. No fertilizer applied.

INDEX.